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CUMULATIVE IMPACT STUDIES IN THE LOUISIANA COASTAL ZONE
• EUTROPHICATION
• LAND LOSS

EDITED BY N. J. CRAIG & J. W. DAY JR.

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Cumulative Impact Studies in the Louisiana Coastal Zone

- Eutrophication
- Land Loss

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Part I • Eutrophication

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ABSTRACT

Eutrophication is a widespread problem throughout the coastal zone of Louisiana. It leads to poor water quality, development of nuisance algal blooms, decline in desirable commercial and sports fishery species, and diminished recreational usefulness of water bodies. The major cultural sources of nutrients leading to eutrophication are urban runoff, domestic sewage, and agricultural runoff.

Basins across the coastal zone were examined for water quality. Lake Pontchartrain Basin, Barataria Basin, Terrebonne Basin, Atchafalaya Basin, and Calcasieu Basin all had serious problems of eutrophication.

Eutrophication can be controlled and is reversible. If direct introduction of nutrient-laden water into aquatic bodies is eliminated, the water bodies will eventually return to a less eutrophic state. The length of time for this to take place depends on the duration and intensity of historical nutrient input. Land treatment (overland flow) offers a viable means of treatment of nutrient wastes.

The understanding and solution of the problem of eutrophication in the coastal zone must be considered within the context of the hydrologic unit. The whole drainage basin or watershed must be considered the fundamental unit of study.

We have outlined a methodology (trophic state analysis) which we believe can be used to classify water bodies in the coastal zone according to trophic status.

INTRODUCTION

The coastal zone of Louisiana contains approximately 7.5 million acres of wetland and water bodies. The wetlands include fresh swamp, and fresh, brackish, and saline marshes. These wetlands are interspersed with numerous shallow lakes, bays, sounds, and ponds which are extensively interconnected by rivers, bayous, passes, and canals. These systems are unified by hydrology and their health depends on water quality.

In many areas across the coastal zone, water quality is deteriorating to critical levels. Many of the lakes in the coastal zone are eutrophic or rapidly approaching eutrophy. This is the cumulative result of numerous interacting factors, many of which are cultural. Domestic wastes are becomming an increasing problem due to inadequate treatment and population growth. Additionally, urban runoff is a significant source of pollution from our cities. Concreted, impermeable areas increase the surface runoff into storm sewers, allowing direct introduction of the waste from our streets into receiving water bodies. Agricultural runoff results in large quantities of nutrients from sediment erosion, fertilizers, and animal manure entering lakes via drainage canals. Wastes from industrial sites are also sources of high nutrient input. Natural sources of nutrients are precipitation, waterfowl waste, detritus, and sediment recycling.

The objectives of this paper are:

1) To develop quantitative indices for measuring eutrophication based on data from the Barataria Basin. These indices include a trophic state index, phosphorus loading rates, and biological indicators of eutrophication.

2) To apply these indices to other areas of the coast in order to determine the trophic status in the coastal zone.

3) To indicate areas where data is insufficient to determine trophic conditions.

4) To suggest management guidelines which could have significant ameliorative impact.

EUTROPHICATION

Definition and Background

Eutrophication can be defined as the natural or artificial addition of nutrients to water bodies and the effects of these added nutrients (Rohlich 1969). Although eutrophication is a natural process, it has been accelerated in many cases by the activities of people. It often results in undesirable changes in water quality, causing destabilization of natural communities, with the advent of algal blooms leading to the development of obnoxious species, and, eventually, to anoxic conditions.

The classic terms 'oligotrophic,' 'mesotrophic,' and 'eutrophic' are used in reference to the trophic status of lakes. The typical oligotrophic lake is clear, deep, and nutrient deficient, while a eutrophic lake is shallow, nutrient-rich, with frequent algal blooms. In Louisiana, however, the spectrum of trophic states ranges from mesotrophic to hypereutrophic because the coastal wetland systems are naturally shallow and evolved with high nutrient loading. There seem to be no natural oligotrophic water bodies in the Louisiana coastal zone.

Bayous and streams in the coastal zone follow the same trophic stages as lakes because of similar characteristics. Most streams are shallow and sluggish and have biological and chemical characteristics comparable as lakes. Only certain physical factors such as wave-induced turbulence are significantly different. The effects of prolonged eutrophication result in similar changes in community structure, such as anerobic benthic communities, blue-green phytoplankton, and pollution tolerant fish species.

Differential Effects in Coastal Zone

Eutrophication can occur from fresh to marine conditions; therefore, all environmental units (swamp, and fresh, brackish, and saline marshes) are susceptible. The effects of eutrophication are similar in all areas, although the characteristic species recognized as biological indicators may be different. *Microcystis*, *Anabaena*, *Anabaenopsis*, and *Spirulina* are common eutrophic freshwater phytoplankton. Brackish and saline forms tend to be small, such as *Monodus*, *Nanochloris*, and *Stichococcus*.

In general, the upper basins (freshwater areas) tend to be more susceptible to eutrophication. This is due to three factors. First, flushing is less in the fresh areas than near the coast because there is little or no tidal action in these areas. Second, the bulk of cultural enrichment occurs in fresh or slightly brackish areas. Finally, the "nutrient trap" of brackish waters tends to lower nutrient levels in the lower basin.

Eutrophication and the Nursery Zone

It has been well documented that estuaries serve as nursery grounds for most commercially important Gulf of Mexico crustaceans and fishes.

Examples of marine species using the estuaries as nursery grounds are the croaker (Micropogon undulatus), sand sea trout (Cynoscian arenarius), sea catfish (Arius felis), menhaden (Brevoortia patronus), shrimp (Penaeus sp.), striped mullet (Mugil cephalus), bay whiff (Citarichthyes spilopterus), and the blue crab (Callinectes sapidus) (Day et al. 1973). The nursery ground is generally defined as an area from the mesohaline (5 ppt to 18 ppt) to lower portion of the polyhaline (18 ppt to 30 ppt), where juvenile stages of various marine species spend the fast-growing phase of their life. Recent work has shown that some freshwater areas are important nursery zones (Hinchee, CWR, unpublished). Our use of the term will be inclusive of those species, such as the oyster, which spend their entire life in the nursery zone.

The effects of eutrophication on the nursery zone in other coastal areas has been well documented (New York: Rhyther 1954; Galtsoff 1956; Barlow et al. 1963; Jeffries 1962, 1964; Dean and Haskin 1964; Chesapeake Bay area: Brehmer 1964, 1967; Massman et al. 1962; Fournier 1966; Sharpiro and Riberie 1965. North Carolina: Odum and Chestnut 1970; Kuenzler and Chestnut 1971. Fjords: Braarud 1945. Biscayne Bay: Lynn and Yang 1960; McNulty et al. 1960; McNulty 1961. Louisiana: Craig and Day 1976. The West Coast: Welch 1968; Gibbs and Isaac 1968; Riesh 1960; Hume et al. 1962).

Range of the Nursery Zone

The exact extent of the nursery zone in Louisiana has not been delineated. Although a large proportion of commercial fishes and crustaceans are known to be estuarine dependent, their use of the Louisiana marsh-estuarine system as nursery grounds has been rarely quantitatively documented.

Two major studies of the use of Louisiana marsh areas (as opposed to open bays and lakes) as nursery grounds were of brackish marshes on Marsh Island (Herke 1971) and intermediate marshes bordering Lake Pontchartrain in St. Charles Parish (Hinchee, unpublished). Although some marine nektonic species are known to migrate throughout the entire coastal area, including fresh marsh and swamp-forest zones, there is presumed to be a rapid decline in use of wetland areas by marine larval and juvenile forms as salinity drops below brackish levels. The distribution of many nursery ground species is apparently strongly influenced by their minimum salinity tolerance, and this tolerance often decreases as the fish grow (i.e., juvenile fish can tolerate lower salinities; Herke 1971).

It has been long assumed that larval brown shrimp, *Penaeus aztecus*, require relatively high salinities (10-15 ppt; see St. Amant et al. 1965). There is now some evidence, however, that in Louisiana juvenile brown shrimp as well as juveniles of other important species actually migrate into low-salinity waters for much of their development (Herke 1971, Wagner 1973, Crowe 1973, Hinchee unpublished). In Galveston Bay, Tex., Parker (1970) found brown shrimp abundant from salinities of 0.9 to 30.8 ppt, with shrimp being very abundant at salinities lower than 5 ppt. Work in upper Trinity Bay marshes (Baldauf et al. 1970) showed these areas to be important nursery grounds. An ecological study of the Calcasieu lobe and river in southwestern Louisiana is presently being carried out by W. Stickle of the LSU Zoology Department. Preliminary results show that juvenile forms are abundant in low-salinity waters. The nursery areas of white shrimp, *Penaeus setiferus*, are unknown and could also be low-salinity areas (Herke 1971).

Seasonal Effects of Eutrophication

Normally algal blooms and oxygen problems associated with eutrophication will occur in the warmer months of the year. In Lac des Allemands there are extensive blue-green algae blooms consisting mainly of *Microcystis*, *Anabaena*, *Anabaenopsis*, and *Spirulina* from April into October (Day et al. 1977). A study of Great South Bay/Moriches Bay complex in New York shows heavy growths of algae develop in early spring and persist through the summer and fall with the months from May to September having optimal temperature range for the bloom algae, *Nanochloris* and *Stichococcus* (Rhyther 1954).

Other studies have shown algal blooms occurring during winter months. In North Carolina, intense *Monodus* blooms occurred from November through April in brackish ponds fertilized with secondary sewage wastes. The warm months of May through September were nonbloom periods (Kuenzler and Chestnut 1971). The size, density, and ecology were similar to the forms found in Great South Bay.

The effects of prolonged eutrophication are permanent, regardless of time of seasonal blooms, because they lead to similar changes in community structure (such as blue-green phytoplankton, anaerobic benthic communities, and pollution-tolerant fish species).

Sources of Eutrophication

The primary nutrient sources of eutrophication in the coastal zone are municipal sewage, industrial wastes, urban runoff, drainage from agricultural land, and natural sources (detrital, waterfowl waste, precipitation, sediment recycling). Uttormark et al. (1974) notes when considering the flow of nutrients, in a strict sense, there are no sources or sinks, rather, a multitude of cyclic pathways along which nutrients are transported. Sources are points along these nutrient pathways.

The sources mentioned above fall into roughly two categories: point and diffuse (nonpoint) sources. A point source is a location at which nutrients are released in quantity and concentration compatible with practical means of nutrient removal. A diffuse source is an area from which nutrients are exported in a manner not compatible with practical means of nutrient removal. These are important concepts for management purposes (Uttormark et al. 1974). Municipal sewage effluent and industrial wastes are point sources, while urban-storm and agricultural runoff are diffuse sources. The specific contributors of nutrients in municipal sewage are mainly human waste and detergents, and in agricultural runoff, chemical fertilizers, animal excretion, and erosion of topsoil.

Domestic Waste

Domestic wastes, stemming from point sources, could conceivably be controlled by proper waste treatment. Inadequate treatment is an increasing problem in the coastal zone as urban centers grow. In many urban areas (Houma, Jefferson parish, N.O.) numerous sewage bypasses periodically dump raw sewage into lakes and waterways. Even if secondary treatment (removal of BOD) were completely implemented, effluents from secondary treatment plants would still lead to eutrophication because of high inorganic N and P level. It is unlikely that tertiary treatment plants (for removal of inorganic nutrients) will ever be built because of high costs (see Meo et al. 1975).

Urban Runoff

Urban runoff is rich in nutrients from lawn fertilizers, animal excretion, leaves, and sediment erosion. All of the filth from our streets--residue from gasoline stations, exhaust fumes settling from cars, litter--drain into storm sewer system allowing direct introduction into receiving streams and canals. (Urban runoff is also high in toxins and heavy metals.) Concreted, impermeable areas increase the amount of surface runoff. Thompson (1970), in a study of land drainage in metropolitan Detroit, indicated that erosion from areas under development contributed 155 metric tons of sediment per hectare per year compared with an overall average erosion rate of approximately 7 metric tons per hectare per year for the metropolitan area. Surburban residential development, where land is stripped for subdividing, and road construction can account for significantly large amounts of sediment even if total acreage under construction is low (Uttormark et al. 1974).

Agricultural Runoff

Agricultural runoff is a major contributor to the nutrient enrichment of water bodies in the coastal zone. The amount of nutrients in runoff and the quantity of runoff itself depends on type of farming, soil retention capacity, and fertilizer practices. A significant part of fertilizers applied to crops reaches natural waters (Holt et al. 1970, Kunishi et al. 1972, and Gilliam and Terry 1973). According to Gilliam and Terry (1973), the portion of fertilizer recovered in yield is roughly 50 percent. The main nutrient inputs from agricultural runoff in Louisiana seem to be nitrogen from sugarcane and phosphorus from sugarcane and rice. For sugarcane grown on Recent alluvial soils in Louisiana, only 38 percent of the nitrogen and 59 percent of the phosphorus is recovered in the yield (Hinchee unpublished).

C. Hopkinson (CWR unpublished) determined amounts of phosphorus in runoff due to sediment erosion and fertilizer excess for crops in the coastal zone. The amount of phosphorus lost due to sediment erosion is 4.3 lb P/acre (average for all crops). The input of P due to fertilizer excess is 10 lb P/acre for sugarcane, 145 lb P/acre for vegetables and orchards, 54 lb P/acre for corn, and 12 lb P/acre for rice.

Industrial Waste

Industrial wastes are point sources of high nutrient input. Wastes from industry often have the added deleterious effect of highly toxic byproducts and heavy metals. Most industry in the coastal zone is situated on the major rivers and bayous for transportation purposes and also because of large water requirement in these industries. Industries often have insufficient wastewater treatment and generally treatment is not updated as expansion occurs (Burk and Associates, Inc. 1973; Page et al. 1976; and Frileux 1971).

Natural Factors

The natural factors affecting nutrient enrichment of water bodies are the hydrology of the particular basin, (i.e., turnover time of lake), size of drainage basin, type of soil in basin, type of bottom sediments, geochemistry of basin, and climate (i.e., precipitation and thermal structure) (Brezonik 1969).

Natural sources of nutrients are waterfowl waste, detritus, lichens, sediment recycling. Precipitation introduces nutrients into the system but the source of the nutrients in the rain may be cultural. Precipitation is often considered a transport vector rather than a source (Uttormark et al. 1974).

Indices of Eutrophication: Phosphorus Loading and Trophic State Index

Phosphorus Loading

Historically, indices for eutrophication have included such things as pounds of BOD; change in community structure using key fish, benthic, and plankton species; diversity; productivity; nutrients; and secchi depth. In current trophic studies of lakes, more attention is given to the nutrients, phosphorus, and nitrogen, the widely recognized limiting factors in lakes. As a general rule, increased nitrogen and phosphorus will lead to increased plant production, i.e., algal blooms, etc. Although no strict guidelines for nutrient input to in-lake concentrations are available, several rigorous studies have determined tentative values for critical concentrations and loading rates for nitrogen and phosphorus (See Tables 1 and 2).

TABLE 1. CRITICAL CONCENTRATIONS AND CRITICAL LOADING RATES FOR NITROGEN AND PHOSPHORUS.

A. Reference:	Rate	LOADING			
		Permissible (up to)		Dangerous (in excess of)	
		N	P	N	P
Shannon & Brezonik (1971)	Volumetric ($g/m^3/yr$)	.86	.12	1.51	.22
Ibid	Areal ($g/m^2/yr$)	2.0	.28	3.4	.49
Vollenweider (1968) for lakes <5m	Areal ($g/m^2/yr$)	1.0	.07	2.0	.13

TABLE 2. PERMISSIBLE LOADING LEVELS FOR TOTAL NITROGEN AND TOTAL PHOSPHORUS (BIOCHEMICALLY ACTIVE) $g/m^2/yr$ (VOLLENWEIDER 1968).

Mean Depth Up To	LOADING			
	Permissible (up to)		Dangerous (in excess of)	
	N	P	N	P
5m	1.0	0.07	2.0	0.13
10m	1.5	0.10	3.0	0.20
50m	4.0	0.25	8.0	0.50
100m	6.0	0.40	12.0	0.80
150m	7.5	0.50	15.0	1.00
200m	9.0	0.60	18.0	1.20

Phosphorus loading was selected as an appropriate measure of nutrient enrichment for the following reasons:

1) In many aquatic systems, phosphorus availability has been shown to be an important factor governing primary productivity, and thus potential eutrophication. While loading is not an absolute measure of availability to plants, it is directly related and provides a good estimate until a detailed budget is available showing rates of export and loss to the sediments.

2) Phosphorus, rather than nitrogen, has been used as a "tracer" of artificial nutrient enrichment, because it has a simpler chemical behavior and is better conserved in an aquatic system. Nitrogen moves through four oxidation states (NH_4^+-N, NO_3^--N, NO_2^--N, Org-N) and is subject to fixation by algae from the large atmospheric pool and to loss through denitrification. Phosphorus has only two forms, orthophosphate (PO_4^{3-}-P) and organic -P, and it is not exchanged with the atmosphere.

While future research may show nitrogen rather than phosphorus to be the limiting nutrient in some of the areas in this study, it can be assumed that loading rates for each will be positively related. When streams or canal waters are contaminated with domestic waste or fertilizer runoff, they are generally rich in both phosphorus and nitrogen. Thus, we are using P loading as an index of all the factors which lead to eutrophication.

Trophic State Index

The measurement of the eutrophic conditions or the trophic state of a water body has been a difficult concept to define quantitatively. As previously mentioned, numerous techniques have been developed as indices of eutrophication, such as species diversity, primary productivity, and plant nutrient levels. The concept of eutrophication, however, is multidimensional and interdependent, begging a broader approach than can be conceived when utilizing only one or two components of the system. Brezonik and Shannon (1971) developed a technique for Florida freshwater lakes that quantifies the trophic state of the water by combining seven indications of water quality into one term or factor. Qualitative speculation can be tested with multivariate analysis techniques in the form of a quantitative index of the trophic state of water bodies. This trophic state index can be utilized in predicting water quality levels through estimates of nitrogen and phosphorus loadings.

Trophic state indices (TSI) have been developed for freshwater lakes in Florida (Brezonik and Shannon 1971) and freshwater rivers and lakes in North Carolina (Weiss and Kuenzler 1976). A similar index has not been developed for an estuarine area. As fresh water enters estuarine conditions, changes in the physical and chemical parameters cause large amounts of nutrients to be deposited in sediments. Currents plume and decrease in speed upon entering the estuary, causing the nutrient-rich particulate matter to settle to the bottom (Hobbie 1976). Clay particles which are in colloidal suspension in freshwater, clump when entering brackish waters. These large particles and flakes sink, carrying with them absorbed nutrients. In addition the back and forth action of the tide allows more time for nutrients to be incorporated into biological and chemical cycles. These processes collectively are the common 'nutrient trap' of estuaries. These unique processes require a different selection and interpretation of parameters (variables) than in fresh water to form an estuarine trophic state index.

Multivariate Analysis. The trophic index is developed by use of the multivariate technique, factor analysis (also referred to as Principle Component Analysis). A multidimensional phenomenon such as eutrophication is difficult to invision. A simplification procedure is needed that will identify major patterns of eutrophication from a multitude of descriptive variables, such as nitrogen, phosphorus, secchi depth, chlorophyll a. Once these variables have been selected, data is collected from a variety of lakes, bayous, and canals. The levels of variables differ

each area forms an axis and the combination of these axes describes a multidimensional space. The response of all areas to a specific variable is plotted as a single point. When each variable has been identified in this manner, the variables with similar response are clustered together. In factor analysis, these clusters of variables are called patterns or factors. The factor is composed of a weighted score or factor loading for each variable designating its relative contribution to the factor. These are then applied to each variable within an area by multiplying its factor loading by each variable and adding to other variables in that area. In this way, each area will be represented by one score and can be interpreted as a relative index number for eutrophication.

BARATARIA BASIN

The examination of eutrophication in the Barataria Basin was approached by two methods. The first approach was to estimate phosphorus loading of various waterbodies within the basin. The cumulative impact of eutrophication and salinity intrusion on the nursery grounds of the basin were assessed. The second was a more thorough approach leading to the development of a trophic state index. Both studies compliment and substantiate each other.

Description of Area

The Barataria Basin is an interdistributary bay-wetland system bordered by Bayou Lafourche, the Mississippi River, and the Gulf of Mexico. The coastal wetlands of the basin, extending from the fresh swamp of the upper basin to the saline marsh bordering the coast, serve as water storage reservoirs, nursery areas, chemical transformation factories, and sources of organic matter and nutrients.

Barataria Basin is responsible for about 45 percent of Louisiana's total commercial fishery harvest, including menhaden, trout, croaker, crab, shrimp, oyster, catfish, and crawfish (Lindall et al. 1972). For 1974, this was approximately $39.6 million dockside value (U.S. Nat. Mar. Fish. Serv. 1975).

Nursery Grounds in Barataria

The nursery grounds in Barataria extend from the upper estuarine areas such as Lake Salvador and Lake Cataouatche to Barataria-Caminada

Bay area. For the oyster (Crassostrea virginica Gmelin), the upper reaches of Barataria Bay/Little Lake complex have become more and more dependable as culture grounds (Van Sickle et al. 1976). Juvenile blue crabs (Callinectes sapidus) spend part of their life cycle in upper estuarine areas such as Lake Salvador (Jaworski 1972). The overlap of the different nursery grounds of the various species gives the general range of the nursery zone--A broad zone from Barataria Bay Salvador will include the most important nurseries.

Sources of Eutrophication

The specific sources of eutrophication in the Barataria Basin are sewage, urban runoff, drainage from agricultural land, and natural sources. The upper basin is heavily loaded by agricultural runoff from sugarcane (46%), soybeans (9%), fallow (crop failure and crop rotation, 35%), and other crops such as corn, vegetables, and wheat (10%) (Hopkinson unpublished). The urban runoff and municipal sewage from westbank New Orleans and surrounding suburban areas input high nutrient loads into Lake Cataouatche, Lake Salvador, and the intracoastal waterway.

This encroachment of eutrophication from the upper basin into brackish nursery grounds could seriously threaten the commercial fisheries of the Barataria Basin.

Salinity Increase and Phosphorus-Loading

Salinity Increase in Barataria

There are trends toward increased salinity in much of the coastal zone of Louisiana (Lindall et al. 1972, Pollard 1973). These changes reflect several factors: (1) Leveeing of the Mississippi River resulting in loss of freshwater input to the upper basins; (2) land loss and inlet widening; and (3) specific projects such as the Mississippi River Gulf Outlet and the Barataria Waterway.

Two ecological effects of the salinity changes in Barataria Bay are changes in the position of vegetation zones and oyster producing areas. The saline-brackish marsh and brackish-fresh marsh boundaries are moving inland.

A historical examination of oyster leases shows a movement of the prime producing areas into the upper estuaries. In 1910 oyster reefs were located in the southern half of Barataria Bay, the northern half having never produced oysters because of low salinity (Van Sickle et al. 1976). By 1947 the northern half of Barataria Bay was a reliable area for natural spatfall (settlement of oyster larvae). By the 1950s, the upper bay leases had become the most valuable (Van Sickle et al. 1976). In the low rainfall years of the 1960s there was natural oyster growth in Little Lake and by 1975 there were 4,000 acres of water bottoms leased in Little Lake (Van Sickle et al. 1976). The optimum salinity range for oysters is 5-15 ppt (Galtsoff 1964), so as salinity increases, oysters naturally move inland. The seaward range of oyster production is limited by predation by the conch (*Thais haemestoma*), which cannot survive salinities below 10 to 15 ppt. Oyster fishermen have noted conchs in upper bay areas more and more frequently in previous years.

Salinity Data, 1898-1910. Van Sickle et al. (1976) note, "the salinity for the area of Grand Terre usually lies within the poly-haline, 18 to 30 ppt." For our purposes an average of this range was taken to represent salinity at the southern end of Barataria Bay. The salinity for St. Mary's Point, the northern end of the bay, was estimated to be approximately 6 ppt around 1898-1910 (Van Sickle et al. 1976). Little Lake was considered fresh around the turn of the century because it harbored a continuous population of largemouth bass (Moore and Pope 1910).

Salinity Data, 1961-1974. The salinity data for St. Mary's Point, Grand Terre, and Lafitte were averaged over the years 1961-1974 from annual averages of salinity for each year. Approximate salinity levels for the three stations were Grand Terre, 20 ppt; St. Mary's Point, 13 ppt; and Lafitte, 3 ppt (Van Sickle et al. 1976).

Salinity Projection for Year 2000. The salinity for the year 2000 was based on the predicted increase of salinity of 0.009 ppt/month at St. Mary's Point (Van Sickle et al. 1976). This value was used for Lake Salvador and Little Lake.

Phosphorus-Loading

Description of Barataria Basin's Areal Divisions. For quantification of phosphorus-loading, the Barataria Basin was divided into three areas (See Fig. 1): the upper basin (Area 1) is bounded by the Mississippi River, Bayou Lafourche, and Highway 90; Area 2 is bounded by Highway 90, Bayou Lafourche, the Intracoastal Canal, and the Mississippi River levee; Area 3, the lower basin, is bounded by the Intracoastal Waterway, Bayou Lafourche, the Gulf, and the Mississippi River. The major water bodies are Lac des Allemands (Area 1); Lake Salvador and Lake Cataouatche (Area 2); Little Lake, Bay L'ours, Round Lake, Bayou Perot, Bayou Rigolettes, Barataria Bay, and Caminada Bay (Area 3).

Present Estimate of Phosphorus Input. Area 1: The current total input of phosphorus into Lac des Allemands (Area 1) is 4.3 $g/m^2/yr$

(Butler 1975). Area 2: The current phosphorus loading rate for Lake Salvador is 0.97 $g/m^2/yr$ and 1.6 $g/m^2/yr$ for Lake Cataouatche. These were obtained by summing estimated inputs of P from municipal sewage, urban runoff, agriculture, and the upper basin. P input was calculated from Table 3. The amount of phosphorus in urban runoff from the West Bank of New Orleans entering Lake Cataouatche is 14 metric tons. This was computed by multiplying the West Bank population of the New Orleans area, 153,939 (U.S. Dept. of Commerce 1970) by the average amount of $PO_4^=$ in storm water runoff produced per person per year on the East Bank (90 g/yr; Stern and Stern 1969). P input from the upper basin (Area 1) is 154 metric tons. Agricultural input of P into Area 2 was estimated to be 43 metric tons/yr. We assumed that the ratio of P input to area of agricultural land in the upper basin (281 metric tons/187 mi^2, Butler 1975) held for Area 2. The P input of the upper basin includes P exported as detritus from wetland, as well as from agriculture, therefore our estimate for Area 2 would include both sources. We believe that agriculture represents the primary source in Area 1 (Day, CWR, unpublished). Agricultural land area in the basin was digitized with a Calmagraphic 11 digitizing system from USGS 1:250,000 scale map. Revisions of the USGS 1:250,000 scale maps from NASA high altitude color infrared photographs were used to update areas of agricultural land.

Total P input to Area 2 for Lake Salvador and Lake Cataouatche was computed as fol:

Lake Salvador		Lake Cataouatche	
upper basin	154 metric tons	urban runoff	14 metric tons
sewage	0.3 metric tons	sewage	33 metric tons
agriculture	21.5 metric tons	agriculture	22 metric tons
	175.8 metric tons		69 metric tons

TABLE 3. AMOUNT OF PHOSPHORUS DISCHARGED FROM PRESENT MUNICIPAL SEWAGE LOCATIONS IN BARATARIA BASIN.

	Pg/yr (10^6)	P lbs/yr
Lafourche	0.05	.00011
Marrero	17.90	.039
Bridge City	2.56	.006
Westwego	7.67	.014
Donaldsonville	5.11	.011
Avondale Homes	2.56	.006
Harvey	3.68	.008
Terrytown #1	4.55	.010
Terrytown #2	50.30	.1107
Southwood West and Timberlane Subdivision	0.31	.00068
Live Oak Manor	0.41	.000902
Florahzae Subdivision	0.20	.00044
Floral Acres Subdivision	0.26	.000572
Ascension Sewer District	0.38	.000836
St. James Sewer District	0.38	.000836
St. James Sewer District	1.38	.000836
Lakewood West Subdivision	1.23	.002706
Grand Isle	1.73	.0038
Lafourche Sewer District #2	0.28	.00062
Golden Meadow	2.07	.0045
Larose	.21	.00046

The average discharge of untreated, primary or secondarily treated sewage from present municipal sewage discharge locations for Barataria Bay Basin (Burk and Assoc., Inc. 1973) was multiplied by an average of the typical range of phosphate concentrations in domestic untreated, primary and secondary sewage (Echelberger et al. 1969).

Typical ranges of phosphate concentrations in various hydrological lake inputs

Input Source	Orthophosphate (mg/l as P)
Domestic Wastewater	
1. Untreated	1.0 - 10.0
2. Primary	0.5 - 9.0
3. Secondary	0.1 - 7.5
4. Tertiary	0.03- 0.30

The areas for Lake Salvador and Lake Cataouatche, 182 x $10^6 m^2$ and 43 x 10^6, respectively, were digitized. The total area of the water bodies was divided into the total phosphorus input to give a P loading of 97 g/m^2/yr for Lake Salvador and 1.6 g/m^2/yr for Lake Cataouatche.

Phosphorus Input for Years 1898-1910. For the years 1898-1910, the phosphorus loading was assumed to be below eutrophic conditions, i.e., less than 0.4 g/m^2/yr (Vollenweider 1968, Brezonik and Shannon 1971; See Fig. 2).

Projected Phosphorus for Year 2000. The phosphorus-loading levels for the year 2000 are based on projections for urban development in the Barataria Basin. We assumed the ratio of the present amount of phosphorus entering Lake Salvador-Lake Cataouatche from the area of urban development existing today would hold for future phosphorus levels in relation to projected urban development areas. (The areas for both time periods were digitized with a Calmagraphic 11 digitizing system from a USGS 1:250,000 scale map.) We assumed close to maximum development along the Mississippi River in Area 2 and the completion of the Bayou des Familles development project. In Area 3 we assumed construction of the Lafitte-Larose Highway below the Intracoastal Waterway and subsequent development of areas between. Phosphorus input to Barataria Bay was calculated by amount of phosphorus loading owing to development divided by phosphorus retention capacity of Little Lake. These are obviously rough estimates, but they serve to point out the consequences of continued development in the wetland.

Phosphorus Retention Capacity in Lac des Allemands, Lake Salvador, and Lake Cataouatche. The phosphorus retention capacity (percent of P input retained) for Lake Salvador was calculated in two ways. One method was to assume that the ratio of phosphorus retention of Lac des Allemands, 127 metric tons, to its area, 65 km^2, would be applicable to Lake Salvador. Using this ratio we estimated that Lake Salvador could retain 440 metric tons of phosphorus. A second method was to use the relationship between areal water load (qs) and phosphorus retention (Rp) (Kirchner and Dillian 1975, See Fig. 2). The areal water load of a body of water ($m\ yr^{-1}$) is calculated as its outflow volume (m^3/yr) divided by its surface area (m^2). The outflow was estimated by assuming the only hydrologic input to the upper basin is rain, and that two thirds of the water is lost to evapotranspiration (Day et al. 1977). The areal water load (qs) for Lake Salvador is approximately 3.0 which gives a Rp of .95 or almost 100 percent phosphorus retention. Using this method, Rp for Lac des Allemands is about 0.55 (qs=9.2), which is approximately the value measured by Day et al. The phosphorus retention capacity for Lake Cataouatche is approximately 0.95 (qs=3.1).

Nursery Grounds: Past, Present, and Future

The data on past, present, and estimated future phosphorus loading and salinity levels at various locations in the Barataria Basin are summarized in Figs. 2, 3, and 4. For the years 1898-1910, there was no eutrophication in the upper basin and high salinity was limited to southern Barataria Bay (Fig. 2). This is indicative of a healthy nursery zone.

From 1961-1974 eutrophic conditions began to effect the upper nursery zone. Although no strict upper limit of the nursery ground can be delineated, Jaworski's citing of the decline of annual crab landings in Lake Salvador because of eutrophication may corroborate the decline of the nursery zone shown in Fig. 3.

If present trends continue, by the year 2000 there will be a drastic decline and perhaps destruction of the nursery zone in Barataria Basin (See Fig. 4).

The projection of eutrophication increases into the future (for the year 2000) shows the extreme importance of limiting any future development below the Intracoastal Waterway. Future development in Area 2 (Fig. 1) will greatly increase eutrophication of Lake Salvador, further stressing nursery grounds there. Lake Salvador may be capable of absorbing the increased phosphorus loading rate, but the upper limit of phosphorus retention capacities is not known. Below Lake Salvador a bottleneck exists in Bayou Perot and Bayou Rigolettes. Saltwater intrusion has resulted in oyster leases in Little Lake. Recently, in years of low rainfall, oyster leases have been productive at the extreme north end of Little Lake. Accompanying the saltwater intrusion are conchs that limit the oysters southerly. Development below the buffer zone of Lake Salvador, such as development along the proposed Lafitte-Larose Highway, will create eutrophic conditions in Little Lake and cause the area of healthy oyster grounds to be degraded or destroyed. This eutrophic situation coupled with rising salinity could sharply delimit the entire nursery zone, seriously affecting commercial fisheries for other species such as crab, shrimp, and fish.

Trophic State Index

Over the past two years we have carried out an investigation of water quality at 23 stations covering the length of the Barataria Basin. The following discussion of basin chemistry and trophic state analysis is based on the data collected during this transect.

Description of Chemistry in the Basin

The chemical interactions and water quality of the Barataria Basin are the result of interactions of vegetation type, changes in salinity, and cultural factors. In the freshwater swamps, organic acids rich in tannins and lignands from decaying vegetation produce characteristic coffee-colored water. This dark water draining from the swamp contains high total phosphorus and organic nitrogen concentrations but very low inorganic nitrogen (i.e., ammonium, nitrate, nitrite). Low inorganic nitrogen may be the result of rapid denitrification and uptake by bacteria. Clean bayous are characteristically clear, dark, and sluggish. Heavy agricultural runoff from sugarcane fields results in murky water and altered nutrient conditions. This is now the most common condition of swamp bayous.

The swamps grade into freshwater marshes and lakes. Lac des Allemands, the uppermost lake in the Basin, receives especially high quantities of agricultural runoff from various bayous. This has caused accumulation of nutrients and dense algal blooms (Day et al. 1977). Some phosphorus is stored in the sediments and some nitrogen denitrified. In Lac des Allemands, the sediments are likely near saturation and their capacity as a nutrient sink is greatly diminished. This allows significant quantities of phosphorus and nitrogen to be flushed out of the lake into Bayou des Allemands (Day et al. 1977).

Saline water has intruded into Bayou des Allemands occasionally as evidenced by the recovery of live *Rangia* clams in thebbottom sediments north of U.S. Highway 90. The bayou appears to retain some of the incoming nutrient material. Phosphorus and total organic nitrogen decrease from the upper bayou to below the town of des Allemands. This consistent drop in nutrient levels may well be a result of salinity. As previously explained, salts will neutralize suspended clays, causing them to precipitate, carrying many adsorbed nutrient forms.

Another significant source of nutrients to Bayou des Allemands is drainage canals such as the Burchell Canal which drains the Simoneaux ponds. It has the highest particulate organic nitrogen levels of the stations sampled and fairly high chlorophyll *a* values.

Bayou des Allemands flows into Lake Salvador where there is a large drop in nutrient concentrations. There is low phosphorus, total organic nitrogen, and resultant high secchi depths. This drop is due to several factors including the large volume of the lake, sorption of nutrients by sediments, increasing salinity, and incomplete mixing of the lake. All of these factors combine to make Salvador a fairly clean water body.

Lake Cataouatche, northeast of Lake Salvador, receives most of its drainage from urban, industrial, and agricultural areas on the Mississippi River natural levee. High nutrient and chlorophyll *a* concentrations are common. The most significant nutrient present is nitrate, an indication of direct agricultural and urban runoff. Nitrate is three times greater than in Lake Salvador, while particulate organic nitrogen is six times greater.

Canals consistently have high nutrient values, especially in phosphorus and nitrate. Bayou Segnette and the Gulf Intracoastal Waterway receive drainage from the west bank of the New Orleans metro area, carrying sewage, industrial wastes, and urban runoff. Bayou Barataria receives drainage from Lakes Salvador and Cataouatche, and Bayou Segnette and the GIWW. The water quality in Bayou Barataria at Lafitte may further be influenced by extensive commercial and private boat traffic, as well as local sewage discharges.

South of Lafitte, Bayou Barataria previously flowed into Bayou Rigolettes. This flow has been altered by the dredging of the Barataria Waterway, producing a deeper channel that allows the enriched bayou waters to bypass natural waterways and flow directly into upper Barataria Bay. Bayou Rigolettes is now largely isolated from upper basin runoff and characterized by very low nutrient levels and high water clarity.

In contrast to Bayou Rigolettes, Bayou Perot is somewhat more enriched and seems to be receiving enriched waters from Bayou des Allemands that have flowed along the western shore of Lake Salvador. Bayous Rigolettes and Perot flow into Little Lake, which is characterized by low nutrients and chlorophyll, and high water clarity. Most of the phosphorus appears to be adsorbed by the sediments and probably not exported.

Little Lake flows into Upper Barataria Bay, contributing clean, filtered water. The Barataria Waterway, another major contributor to the bay, functions like a drainage pipe for waters from Bayou Barataria. The waterway at Manila (Mile 29) has higher nutrients, chlorophyll, and turbidity than Little Lake.

Barataria and Caminada bays are large enough so that the effect of the upper basin drainage is still minimal. Caminada receives water from a smaller and more isolated basin than Barataria. Ho and Barrett (1977) showed that Barataria has twice the nutrient levels of Caminada, reflecting upbasin influences.

Trophic State Analysis

Initial results from the multivariate analysis suggested a source-sink process could explain the existing water quality. This means that the various water bodies were functioning principally as either sources of nutrients, intermediate filtration areas, or nutrient sinks. Practically all areas of the freshwater swamp are highly eutrophic and serve as sources of nutrients. Canals draining agricultural areas, such as the St. James Canal (Fig. 6), contribute the highest nutrient levels in the entire freshwater area. The few remaining clean bayous are an indication that previously the swamp functioned as a nutrient sink. Lac des Allemands under natural, unaltered conditions was probably able to retain most incoming nutrient loads in its sediments and cycling process. It appears now to have reached its capacity as a sink and is an ineffective filtration area. Empirical (Day et al. 1977) and theoretical (Kirchner and Dillon 1974) calculations show that about half of input nutrients are exported to the lower basin.

The brackish and saltwater areas display clear-cut examples of a source-sink process. Phosphorus and secchi depth data provide a good illustration of chemical changes occurring between the various water bodies (See Fig. 7). Relatively high phosphorus enters the Burchell Canal and then into Bayou des Allemands. Secchi depth is extremely low in both areas. As this enriched water enters Lake Salvador, phosphorus out of the water column and secchi depth is high, indicating Lake Salvador is functioning primarily as a sink. The other stations that are clearly sinks are Bayou Rigolettes (17), Little Lake (21), Barataria Bay (24), and Caminada Bay (25). Intermediate filtration areas include Bayou des Allemands, Bayou Barataria (16), Bayou Perot (18), and upper Barataria Bay at Manila (23). These water bodies have not reached their capacity as sinks, but are inefficient in retaining all of the nutrients either because of high loading or rapid flushing. Natural tidal channels draining brackish and saline marshes also contribute nutrients to open water areas and thus serve as natural intermediate filtration areas.

Active sources of nutrients include Lake Cataouatche (13), Bayou Segnette (14), and the Gulf Intracoastal Waterway (15). Nutrients, chlorophyll, and water clarity all indicate that these areas are highly eutrophic (Fig. 8).

Results of Cluster Analysis

Cluster analysis is a statistical technique which can be useful in the elucidation of eutrophication. It involves progressively combining data from various water bodies into smaller and smaller groups according to the degree of similarity among data variables as in Brezonik and Shannon 1971. In this study the stations were grouped according to their trophic states, as defined by the following variables: total phosphorus, total organic nitrogen, chlorophyll a, secchi depth, dissolved oxygen, and ammonium.

The cluster analysis partitioned the various stations into three groups (Fig. 9). One group consisted of the cleanest stations in the basin. A second group contained primarily freshwater eutrophic stations, while in the third group were mainly brackish and saline stations with some degree of eutrophication.

The clean stations had relatively low nutrient and chlorophyll a concentrations and clear water (group 2). They are mainly brackish stations (Lake Salvador, Bayou Rigolettes, Little Lake, Barataria Bay, and Caminada Pass) but one was a natural swamp stream. These stations are active nutrient sinks as indicated earlier by graphs of phosphorus and secchi depth (Fig. 7).

The second group contained all freshwater stations (group 1). Most waters in the upper basin are highly eutrophic and most of the stations clustered into a fairly homogeneous group. It is difficult to pick out any patterns within this cluster mainly because of the similar water quality of the stations.

There is a range of eutrophic conditions included within the last cluster (group 3). This range is reflected by separate subclusters. One subgroup contains highly eutrophic brackish stations (Lake Cataouatche, Bayou Segnette Waterway, the Intracoastal Waterway, and Lower Bayou des Allemands) as well as one swamp station (3b). The swamps station is the only one where we have never observed measurable salinity. All of these stations exhibit high nutrient and chlorophyll concentrations and low water clarity. This group of stations is very similar to the eutrophic fresh stations and serve as sources of nutrients.

A second group in this cluster consists of stations of intermediate trophic status (3a). The stations within this subcluster appear to function as intermediate filtration areas, absorbing nutrients but unable to remove them from the water column as efficiently as the active sinks. Stations included in this grouping are Bayou Barataria, Bayou Perot, and the Barataria Waterway. It is interesting to note that a natural brackish marsh tidal pond is included here. This gives some indication of the trophic status of natural marsh areas.

In summary, by the use of cluster analysis we have effectively separated various areas of the basin by trophic status. This method also differentiated most fresh from saline areas. We conclude that with further refinement, this methodology will prove very useful in classification of various water bodies in the coastal zone in terms of trophic status.

Phosphorus Retention

Calculation of P retention according to Kirchner and Dillon (1974) indicates that both Lake Salvador and Lake Cataouatche should retain over 95 percent of P input. P loading rates of 0.97 and 1.6 g P m^2/yr^{-1} for Salvador and Cataouatche, respectively, are both higher than the critical value of 0.4. However, there is a striking difference in trophic status of the two lakes. Cataouatche is characterized by high nutrients and chlorophyll levels, and turbid waters. Salvador, on the other hand, has lower nutrient and chlorophyll a levels and clearer water. Lake Salvador is relatively clean while Cataouatche seems highly eutrophic. How then can the similar P loading and retention be reconciled with the different trophic status of the two lakes. We believe difference in circulation patterns, history of phorphorus input, and oxidation condition of the sediments can explain these findings.

The bulk of nutrient input to Salvador is from Bayou des Allemands at the western end of the lake. The principal outlet from the lake seems to be Bayou Perot. Winds from the NW, N, E, and SE would tend to hold water entering from Bayou des Allemands in the western part of the lake or push it towards Bayou Perot. Only SW winds would tend to mix this water over the whole lake. Predominant winds in Louisiana are from the SE or N and NW. Therefore, water entering the lake from Bayou des Allemands would generally tend not to mix over the whole lake but flow in the western part of Lake Salvador towards Bayou Perot. Water clarity, nutrient, and chlorophyll a measurements in these water bodies support this hypothesis.

By contrast, Lake Cataouatche has no one major inlet or outlet. Three important inlets are the Louisiana Cypress Lumber canal from the NW, Bayou Veret (NE), and Bayou Segnette (SE). In addition, there are several smaller inlets. There are two outlets into Lake Salvador and one via the Bayou Segnette Waterway. Because of the number of inlets, smaller size, and shallow depth of the lake, prevailing winds would tend to mix entering water throughout the lake.

There is also a significant difference in the nutrient loading history of the two lakes. We believe that Cataouatche has received high nutrient loads for a longer period of time. Canals were first constructed into the lake in the second half of the 19th century. Because the lake is close to agricultural and urban areas on the west bank of the Mississippi, it has received the bulk of drainage from these areas and has acted as a buffer for Lake Salvador. By contrast, the agricultural areas on the east bank of Bayou Lafourche are separated from Lake Salvador by a larger expanse of marsh. Also, the upper basin which presently serves as the major source of nutrient input to Lake Salvador probably was relatively unimportant as recently as 1020 years ago (Butler 1975). Thus it seems that Cataouatche has received significant nutrient loading over a much longer period of time.

Another significant difference between the two lakes is the nature of the bottom sediments. Even though salinities in the two lakes are similar, Salvador supports extensive populations of Rangia clams while Cataouatche does not (Bahr, CWR, unpublished). Visual observation of sediment samples indicates more extensive anaerobic conditions in Lake Cataouatche.

We believe an examination of these factors can resolve the conflicts in our findings. Sediments generally tend to act as a sink for phosphorus (Syers et al. 1973 review the literature on phosphate c chemistry and lake sediments.). However, sorption studies have shown that some sediments, for example those from Lake Wingia (a eutrophic lake in Wisconsin), are virtually saturated with inorganic P (Williams et al. 1970). Release of PO_4 overlying water occurs if the concentration of interstitial P exceeds that of overlying water (Stumm and Leckie 1971). In addition, P release is much higher if anaerobic conditions exist in the sediments (Syers et al. 1973, Patrick and Khalid 1974).

Thus the application of the P retention index of Kirchner and Dillon must include an appreciation of the conditions of the sediments. So long as sediments can absorb more P, then the relationship holds. We believe that this situation holds for Lake Salvador; For Lake Cataouatche, sediments have become saturated. In addition, anaerobic conditions in Cataouatche favor release of P. Thus it seems that although there is an appreciable amount of P entering Lake Salvador, most is confined to the western end of the lake and the sediments are still an active sink. Cataouatche, on the other hand, has a long history of high nutrient loads and the saturated sediments are probably acting as a source of P. In fact, Syers et al. postulated that "advanced eutrophication enhances release of sediment inorganic P, and it is possible that eutrophic lakes will perpetuate a eutrophic condition" for some time if external sources of P were eliminated.

Factor Analysis

Another statistical tool used in classifying the stations according to trophic status is multivariate factor analysis. Factor analysis is a means by which the regularity and order in phenomena can be discerned. As phenomena co-occur in space or in time, they are patterned; as these co-occurring phenomena are independent of each other, there are a number of distinct patterns. The phenomena we are dealing with in this report are water quality variables. "What factor analysis does is this: it takes many measurements and qualitative observations and resolves them into distinct patterns of occurrence" (Rummel 1968). These patterns are called factors. Factor analysis is discussed in detail by Rummel (1968) and applied to trophic state analysis of Florida Lakes by Brezonik and Shannon (1971).

Factor analysis was run using the following water quality indicators: ammonium, total phosphorus, total organic nitrogen, dissolved oxygen, chlorophyll a, and secchi depth. The first factor or pattern accounted for 49 percent of the total variation among the twenty-three sampling stations. When two factors were considered, 76 percent of the variation was accounted for. The most important parameters in the first factor were phosphorus, chlorophyll, total organic nitrogen, and secchi. For the second factor, the most significant variables were ammonium and dissolved oxygen.

Factor scores of the various stations are plotted in Fig. 9 with the groupings from the cluster analysis enclosed in envelopes. It should be stressed that this graph presents the results of two separate methods; factor analysis and cluster analysis. Factor one seems to be related to level of nutrient input. The freshwater stations (Cluster 1) have the highest nutrients while the clean stations (Cluster 2) have the lowest input. Factor 2 may be related to salinity. Generally, fresher stations have negative scores. For example, station 3, although grouped with the clean station, has a much different score on factor 2 than the other stations, perhaps because it is fresh.

A gradient of trophic status is most pronounced for brackish stations. The most eutrophic stations (Cluster 3b) fall toward the right and top area of the graph while the cleanest stations (Cluster 2 with the exception of station 3) are located toward the left and bottom. Stations of intermediate eutrophy (Cluster 3a) are located between the other two groups. For the fresh area, there seems to be no intermediate stations; only highly eutrophic (Cluster 1) and clean (station 3). Had we sampled intermediate fresh stations, they would likely fall between station 3 and Cluster 1.

Clearly, both cluster analysis and factor analysis are an effective means of classifying water bodies according to trophic status. To apply this technique for the whole coastal zone, the greatest need is for a comparable set of data for all major water bodies. In the past, different parameters have been measured at different sites, and the methods of analysis have not been the same. We believe that we have identified a suitable set of variables, which, if analyzed in the same manner, could be used in classifying the trophic status of water bodies in the coastal zone.

LAKE PONTCHARTRAIN

Lake Pontchartrain is a large, shallow, oligohaline water body located immediately north of New Orleans, La. (see Fig. 10). It is part of an estuarine lake and bay system in which water entering from the Gulf of Mexico mixes with fresh water moving out of a watershed encompassing 13,000 square kilometers. It is part of Hydrologic Unit I of the coastal zone. Over the past 50 years, human population in this drainage area has trebled. While all sections have shown growth, a large percentage of the residential development incurred by the increase has been located in reclaimed wetland adjacent to the lake.

As a consequence of the rapid settlement, many of the natural streams and drainage canals which bring fresh water into Lake Pontchartrain now also serve as conduits for domestic wastes and fertilizer residues rich in nitrogen and phosphorus. These inputs have caused a decline in water quality throughout the lake and are responsible for increased incidence of eutrophic conditions.

An increasingly urban and environmentally conscious public is demanding the preservation of Lake Pontchartrain as a commercial, recreational, and aesthetic resource of high importance. Here we will use phosphorus loading as an index of eutrophication in Lake Pontchartrain.

Phosphorus Loading for Lake Pontchartrain

Phosphorus loading for Lake Pontchartrain was calculated using the following equation:

$$\text{Loading} = \frac{\text{All sources (Flow X concentration of P)}}{\text{Surface area of Lake}} = g/m^2/yr$$

Flow is the sum of major freshwater sources into Lake Pontchartrain. These data were gathered from various sources (Table 4). Pass Manchac, rain, and northshore rivers account for the bulk of freshwater input. The New Orleans area contributes less than 5 percent.

TABLE 4. MAJOR FRESHWATER SOURCES OF LAKE PONTCHARTRAIN

	$10^9 m^3 yr^{-1}$	% Total H_2O Supply
Pass Manchac	5.10	54%
Tangipahoa River	1.53	16%
Rain-Evaporation on Lake	1.42	15%
Tchefuncte River	0.72	7.6%
Bayous Lacombe and Liberty	0.34	3.6%
New Orleans Metropolitan Street Runoff	0.40	4.2%
TOTAL	9.51	

Streamflow data: U.S. Army Engineers 1962
Lake areas: Barrett 1970
Net rainfall: Gagliano et al. 1973
Magnitude of New Orleans Street Runoff: Ponlius et al. 1973, Cramer 1974.

The average P concentrations in each of the freshwater inputs (Table 5) account for seasonal flow variations. For example, if nutrient values are elevated during the spring when flow rates are high, the weighted yearly average will be greater than the mean of all samples taken at regular intervals throughout the year. The poor water quality of urban street runoff is obvious.

TABLE 5. P-CONCENTRATIONS IN FRESHWATER SOURCES INPUT TO LAKE PONTCHARTRAIN

	P-concentration (g/m^3)
Pass Manchac	0.14
Tangipahoa	0.18
Tchefuncta River	0.10
Bayous Lacombe and Liberty	0.10
New Orleans Street Runoff	(2.30 average)
Orleans Parish	1.09
Jefferson Parish	3.50

Pourier and Rogers 1975, Stern and Atwell 1968, Stern and Stern 1969, Kemp and Root, CWR, unpublished; USGS 1975, USGS 1976, Tarver and Dugas 1973.

The total quantity of phosphorus from each source was obtained by multiplying flow times concentrations (Table 6).

TABLE 6. PHOSPHORUS LOADING IN FRESHWATER SOURCES INPUT TO LAKE PONTCHARTRAIN

	P-input (10^8g/yr)	% Total P-input
Pass Manchac	7.14	34%
Tangipahoa	2.75	13%
Aeolian (Rain and dustfall)	1.13	6%
Tchefuncta	0.72	3%
Bayous Lacombe and Liberty	0.34	2%
Jefferson Parish Street Runoff	7.00	32%
Orelans Parish Street Runoff	2.18	10%
TOTAL	2.13×10^9	

Pourier and Rogers 1975, Stern and Atwell 1968, Stern and Stern 1969, Kemp and Root, CWR, unpublished; USGS 1975, USGS 1976, Tarver and Dugas 1973.

While New Orleans metropolitan street runoff is less than 5 percent of freshwater input, it represents over 43 percent of total phosphorus input because of high concentrations of phosphorus in the runoff. Jefferson Parish, with a smaller population, accounts for almost 33 percent of total P input. This may be due to two factors. First, as we stated earlier, developing suburban areas contribute a far greater per capita urban runoff load. Second, during heavy rains much raw sewage is allowed to bypass treatment plants. By contract, most sewage from Orleans parish is pumped to the Mississippi River.

From the total P input and the area of the lake, P loading was calculated as follows:

$$\text{Total Loading} = \frac{2.13 \text{ X } 10^9 \text{ g/yr}^{-1}}{1.61 \text{ X } 10^9 \text{ m}^2} = 1.32 \text{ g P m}^{-2}\text{yr}^{-1}$$

This level of loading indicates that the lake is, on the average, eutrophic. We shall have more to say about this later.

Natural vs. Artificial P-input

To determine what percentage of the total phosphorus loading is natural and how much is the result of artificial enrichment, we estimated the loading under predevelopment conditions. We did this by assuming a direct relationship between current loading and average phosphorus concentrations and also assumed that predevelopment phosphorus concentration in Lake Pontchartrain would be approximately that found in Caminada Bay, a relatively uncontaminated part of the southern Barataria estuary (Ho 1971).

TABLE 7. TOTAL PHOSPHORUS INPUT UNDER PREDEVELOPMENT CONDITIONS

$$\frac{\text{Current loading}}{\text{Current Avg. Conc.}} = \frac{\text{Natural loading}}{\text{Natural Avg. Conc.}}$$

$$\frac{1.32\ g/m^2/yr}{.1\ g/m^3} = \frac{X}{.04\ g/m^3} \qquad \text{(Ho 1971)}$$

$X = .53\ g/m^3/yr$ = Natural P loading.

We assumed that under natural conditions the amount of phosphorus entering the lake through each tributary stream would be proportional to the amount of water flow. To calculate the percent of current phosphorus loading attributable to development in the watershed, the following formula is used:

$$\text{\% Artificial P from source} = \text{Current P input from source} - \text{Total P input under predevelopment conditions} \times \text{Fraction of total } H_2O \text{ input to lake from each source}$$

The artificial input from each freshwater source is given in Table 8. Practically all P from the New Orleans Metropolitan area is artificial.

TABLE 8. ARTIFICIAL P INPUT FROM SOURCES INTO LAKE PONTCHARTRAIN

	Artificial P input (g/yr)	% of total input from source
Pass Manchac	2.55×10^8	36%
Tangipahoa	1.39×10^8	51%
Tchefuncte	0.40×10^7	6%
Bayous Lacombe & Liberty	~ 0	0%
New Orleans Street Runoff	8.84×10^8	96%
TOTAL	1.28×10^9	

Phosphorus Input - Past, Present, and Future

In order to project trophic state Lake Pontchartrain into the future, a common denominator of both basin development and nutrient enrichment is needed. Population is a good index of both. Dividing the figures for artificial nutrient loading developed in Table 8 by the number of people in each subunit of the watershed, yields per capita phosphorus input (See Table 9). The size of this figure is dependent on the type of development and the waste management used in each drainage area. Areas with high agricultural or suburban development have the highest per capita P input.

TABLE 9. PER CAPITA ARTIFICIAL P - INPUT

Drainage	Basin Use	Per Capita Multiplier (kg/person)
Pass Manchac	Urban, Suburban, Agricultural, Natural	0.74
Tangipahoa	Agricultural, Natural	2.03
New Orleans		
Orleans Parish	Urban	0.36
Jefferson Parish	Suburban	1.77

When used in conjunction with population projections based on present growth rates, the per capita multiplier allows the prediction of future loading rates using the following formula:

$$\text{Total P loading} = \frac{\text{Population X per capita multiplier}}{\text{area of lake}}$$

Projections predict a stable population in the City of New Orleans, while the suburban areas of both New Orleans and Baton Rouge are predicted to grow rapidly (See Fig. 11).

These data indicate that Lake Pontchartrain is, on the average, eutrophic now and will become excessively so by the end of the century. Artificial phosphorus input will rise from 57 percent at present to 73 percent by the year 2000. However, as in the case of Lake Salvador, this data must be interpreted in light of other physical, chemical, and biological data (See Table 10 for past, present, and future nutrient loading).

First, the lake is not uniformly eutrophic. The most extreme area is the south shore adjacent to the metropolitan area. This area is characterized by high nutrient and coliform levels and pollution indicative species. The southwestern part of the lake from Jefferson Parish to Pass Manchac seems also to be eutrophic. The northshore and eastern end of the lake are fairly clean because of low nutrient input and more rigorous tidal flushing.

Thus there is a gradient in eutrophic conditions from south and west to north and east. This gradient is due to differential inputs of nutrients and rates of flushing. Phosphorus retention by the sediments is probably also high in the south and west portion of the lake.

TABLE 10. PHOSPHORUS LOADING INTO LAKE PONTCHARTRAIN OVER TIME

	Total P-loading ($g/m^2/yr$)	% Artificial
1900	.64	17%
1920	.70	24
1940	.83	36
1960	1.05	50
1970	1.23	57
1990	1.72	70
2000	1.93	73

Sources of Nutrient Enrichment

The data shows that substantial artificial nutrient enrichment is entering the lake from four major sources. The ranking of these sources is in Table 11.

TABLE 11. ARTIFICIAL NUTRIENT SOURCES FOR LAKE PONTCHARTRAIN

	Artificial P-input (g/yr)	% Total artificial input to lake
Jefferson Parish Street Runoff	6.88×10^8	54%
Pass Manchac	2.55×10^8	20%
Orleans Parish Street Runoff	1.96×10^8	15%
Tangipahoa River	1.39×10^8	11%

Figure 12 gives a visual presentation of the relative importance of each input as a water source and as a nutrient source.

Jefferson Parish, west of New Orleans, contributes 2 percent of the total freshwater input and yet is the origin of 54 percent of the culturally derived phosphorus entering the lake. In contrast, the City of New Orleans, with a higher population, produces only 15 percent. The difference lies in the handling of sewage. In Orleans, sewage is collected, and pumped into the Mississippi River. Water drained by Lake Pontchartrain outfall canals is strictly street runoff. When Jefferson was developed, no city sewage lines were installed. Initially, waste treatment was handled with individual septic tanks. These were placed in great density in an area in which the water table is almost at the surface. Canals dug to drain suburban subdivisions took on the character of raw sewage conduits. While city sewage is now being emplaced, outfall canal water quality is still extremely poor. The waste containment problem is far from solved. Domestic sewage must be prevented from reaching outfall canals. Treatment of outfall canal waters prior to discharge would be impractical because of the volume passed during storms and the expense involved in nutrient removal. The best alternative is to provide a complete sewage collection system designed to deal with the unique engineering problems created by the settling of reclaimed wetland soil. Wastes could be vented to a treatment plant for ultimate disposal in the Mississippi River. The discharge of secondarily treated waste water from Jefferson Parish would probably not appreciably lower water quality in what is already a grossly polluted river. The effect on Lake Pontchartrain would be significant, however,as nutrient input from Jefferson would drop 70 percent. The lake would return to a 1960 nutrient loading.

Conclusion

Census figures show that the Lake Pontchartrain watershed is growing in population faster than any other part of the state of Louisiana. Much of the anticipated development appears likely to occur in reclaimed wetlands east and west of New Orleans. This will be mainly suburban construction of the type currently found in Jefferson Parish. This development is characterized by an extremely high per capita phosphorus discharge (Table 9). If New Orleans East and the St. Charles Parish swamp is converted to suburban residential use without adequate environmental safeguards, eutrophication will, within 30 years, destroy most of the desirable aesthetic, recreational, and commercial values of Lake Pontchartrain. The species shift and water quality decay which are associated with system eutrophy will also have an indeterminate deleterious effect on the large offshore fishery which harvests lakedependent menhaden and shrimp.

TERREBONNE BASIN

Description

The Terrebonne Basin (Hydrologic Unit V) which lies west of the Barataria Basin, is bordered by Bayou Lafourche, the Atchafalaya Basin Protection levee, the lower Atchafalaya River, and the Gulf of Mexico (see Fig. 13). The basin is rich in wetland areas with 484 km^2 of fresh swamp in the northern basin gradiating into marshes (521 m^2) bordering the Gulf (Gane, CWR, unpublished).

To quantify eutrophication we divided the Terrebonne Basin into two areas (see Fig. 13). Area I extends north to the Assumption-Iberville parish line and is bordered on the south by Assumption-Lafourche-Terrebonne parish line. A previous study of the Lake Verret watershed extended the northern boundary beyond the Terrebonne Basin coastal zone boundary (USDA 1976). By close examination of aerial photographs, we determined that the bayous and canals from Iberville Parish bypass the Lake Verret, Grassy Lake, and Lake Palourde area almost entirely and for this reason our study area was reduced. In Area I, commercial, residential, and agricultural land is limited primarily to the natural levees of the Mississippi River and the various bayous. The ratio of high land to swamp is 1:2. Chemical industries are prevalent in the northernmost parishes of the area.

Area II is bounded by the Atchafalaya, the southern Assumption parish line, Bayou Lafourche, and the Gulf. Exclusive of the large bays and sounds, Area II contains 398 km^2 of waterways and waterbodies (Chabreck 1972). Area II is predominantly fresh, brackish and saline marsh. The ratio of high land, swamp, and marsh is 1:1.5:5. Shellfisheries and petroleum production are important in this area.

Sources of Eutrophication

The sources of eutrophication in Terrebonne are similar to those of the other basins. In the upper basin, agricultural runoff primarily from sugarcane fields into the different water bodies results in high nutrient levels. From the available data, industrial waste seems to be the source of extremely high phosphorus inputs, particularly in the Lake Verret region. Municipal sewage from the Houma area is also a source of high nutrient input and is creating serious problems for the shell fisheries in the marshes below. Much of Houma's sewage bypasses any treatment, thus raw sewage is entering the estuary via canals and bayous from Houma. Although the marsh has the ability to absorb much of this nutrient input, the high coliform levels have caused more and more closures of oyster grounds since 1966 (current closures are shown in Figure 14). These waters are monitored by the La. Dept. of Health in compliance with National Shellfish Sanitation Program (HEW) (Van Sickle, CWR, unpublished).

Present Estimates of Phosphorus Input

Area I. The current P-input into Lake Verret was obtained by summing estimated inputs from industrial discharge, municipal sewage, and agricultural runoff. Urban runoff was not considered significantly important because the area lacks any true urban centers. P-input from domestic sewage of Napoleonville and Pierre Part was determined on a per capita basis (P 3lb/capita/yr). Industrial discharge was determined from given phosphorus concentrations and flow data for the industries within Area I (Pollution Control Engineers 1975). Agricultural land in the Lake Verret watershed was determined by existing land use figures (Pollution Control Engineers 1975). Agricultural input was calculated by assuming an export of 2.0 kg of P per acre of agricultural land (Hopkinson, CWR, unpublished). Total phosphorus input into Area I:

sewage	2 metric tons
industry	254 metric tons
agriculture	127 metric tons
	383 metric tons

The total area of Lake Verret (59.3 km^2) was divided into the total phosphorus input to give a P-loading of 6.46 $g/m^2/yr$. This level of phosphorus loading indicates a hypereutrophic condition in Lake Verret, however, this may not be the case. This brings up problems associated with the sole use of P loading as an indicator of eutrophication. The proper use of P loading should be correlated with such factors as hydrology, nutrient concentration, and biological indicators.

The hydrology in this upper basin, as opposed to other hydrologic units addressed in this study, is unclear. Because of this it is difficult to determine if runoff from specific agricultural areas and industrial sites actually have complete input into Lake Verret or bypass the lake partially or entirely.

It is apparent from other data sources that water quality in Area I is being degraded by runoff from agricultural fields, etc. There is a large amount of sediment erosion taking place. Total sheet and gully erosion amounts to 1,486,000 tons per year. It is calculated that 903,000 tons of sediment are deposited in the split ditch system that is part of the sugarcane culture of the area. Deposition in Grand Bayou is approximately 29,000 tons/year. Field ditches other than sugarcane ditches collect 113,000 tons/year of sediment. Northern Lake Verret collects 20,000 tons/year. The remainder (293,000 tons/year) is deposited in main channels, other portions of the swamp, and Lake Natchez. Lake Natchez is rapidly filling from this sediment input (USGS 1976).

Water quality data from 1974-1975 at Bayou Sigur (Station 5), Grand Bayou (Station 4), Lake Verret (Station 3), Grassy Lake (Station 2), and Lake Palourde (Station 1) are given below:

Station	Nitrogen-ammonia (mg/l)	N-Nitrate (mg/l)	Phosphate-P (mg/l)
1	.26	.16	.13
2	.30	.12	.12
3	.66	.10	.07
4	1.30	.48	.22
5	3.80	.88	1.99

(USGS 1976)

This data indicates high levels of nutrients in Bayou Sigur and Grand Bayou which directly drain the sugarcane fields in Area I. It seems that some of this nutrient-laden water becomes diluted when it enters Lake Verret and probably phosphorus is taken up in the sediment as in Lake Salvador. The northern end of Lake Verret is characterized by thick grass beds of <u>Certophyllum</u>, <u>Nais</u>, and <u>Nitella</u> (Paille, CWR, unpublished). These disappear by the middle of Lake Verret.

Lake Verret, like Lake Pontchartrain and Lake Salvador, seems to be characterized by several separate trophic states. In addition, the sediment deposition data reported indicates that much P may be filtered by the swamp deposited sediments. The waters in Lake Palourde are relatively low in nutrients (USGS 1976). This is also supported by 1975 fish population data. Both Grand Bayou and Bayou Sigur have low-oxygen, pollution tolerant species such as channel catfish, spotted gar, and shad and almost no game fish. Lake Verret has much higher population of game fish including bass, white and black crappie, bluegills, and sunfish (USGS 1976). It is apparent that the waters in bayous and channels adjacent to cultivated areas are limiting to fisheries.

Area II. The total phosphorus input for Area II was determined by the same methods as for Area I for sewage, agriculture, and industry. In addition, urban runoff from Houma was included. The total phosphorus input is as follows:

Agriculture--	123 metric tons
Sewage-------	63 metric tons
Industry-----	317 metric tons
Urban runoff-	3 metric tons
TOTAL	506 metric tons

It is difficult to calculate a loading rate for Area II because we were unable to obtain accurate area measurements for water bodies and waterways receiving nutrient input. In addition, because of the complex hydrology, it was impossible to determine which waters were actually receiving wastes. Although we were unable to define the extent of eutrophication using P loading, the large P input coupled with other water quality data points to widespread eutrophication in Lower Terrebonne Basin.

Water Quality

Many of the bayous and bays in Area II have poor water quality primarily from municipal sewage wastes from the Houma area and from industrial waste. Bayou Terrebonne is a problem area, with low dissolved oxygen and high levels of sulfate. The Intracoastal Waterway near Houma has extremely high coliform levels due to the sewage bypass system of Houma. The Houma Navigation Canal shunts wastewater discharge from Houma into the marshes east of Caillou Lake and Lake Mechant, altering water quality by increasing nutrient and coliform levels. Four League Bay has coliform counts averaging consistently and substantially above the limit of 70 set by the National Shellfish Sanitation Program and adopted by the Louisiana Stream Control Commission. The same holds true for Bayou du Large, Lake Mechant, and Lake de Cade. Lake Caillou, Bay Junop, Grand Bayou du Large, and Lower Bayou du Large have <u>average</u> coliform counts within established limits (Pollution Control Engineers 1975). Only the larger bays adjacent to the Gulf are generally clean. As previously mentioned, this has caused a large area of oyster grounds to be closed (Fig. 14).

Conclusion

The bayous and canals draining agriculture and receiving industrial waste in Area I are eutrophic and this high nutrient input has caused Lake Verret to become eutrophic, possibly hypereutrophic in parts.

In Area II, many of the bayous and bays have degraded water quality due to municipal sewage primarily from Houma and industrial waste. This has seriously impacted the shellfisheries of the basin.

For the basin there is expected to be an overall growth of approximately 60 percent in the next 20 years (1975-1995), with increased industrial growth. Much of this growth is projected to occur in the southern part of the basin in the vicinity of Houma (Pollution Control Engineers 1975). Unless adequate and precautionary management measures are taken the entire basin's water quality could be severely degraded and unable to support any type of healthy fishery.

ATCHAFALAYA BASIN

Description

The Atchafalaya Basin is located in south central Louisiana to the west of the Barataria and Terrebonne basins (see Fig. 15). From the junction of the Old River segment of the Mississippi River, the Atchafalaya flows 141 miles (227 km) to the Gulf. It is the largest distributary of the Mississippi River, which drains approximately one-third of the United States. The Old River control structure limits the diversion of the Mississippi River flow into the Atchafalaya to 30 percent. A small additional flow from the Red River inputs into the Atchafalaya. The Atchafalaya Floodway which includes a large part of the natural Atchafalaya Basin between its dikes is an interesting case with regard to water quality in Louisiana. It is the only part of the vast Lower Mississippi River floodplain which still regularly receives floodwater. As pointed out by van Beek et al. (1977), "The artificially achieved shrinkage of the floodplain area has impressed its impact on the ecosystem of the Atchafalaya Floodway primarily through increased flux of riverborne materials entering the area."

The Floodway allows water to rise much higher than it would naturally in the spring. Flooding is even more prolonged than would result simply from the amplication of the floods due to the presence of numerous navigation, pipeline, and well location canals. These watercourses continue to allow flow of water into the deeper swamp and remnant lake basins even during relatively low stage condition of the Atchafalaya River and its various principal distributaries. The increased flux of sediment borne by the river water has produced chronic sedimentation problems which constantly reduce the storage capacity and thereby the utility of the floodway.

Nutrient Input and Loading Rate

Of special interest is the increased flux of nutrients through the floodway. In the lower lying swamp basins water covers the swamp floor for the greater part of most years. In these are extensive and chronic stands of water hyacinth. This situation has been described in detail by van Beek et al. (1974). They considered the extensive (50 km^2) stand of water hyacinth which persisted from year to year in the area of the floodway known as Buffalo Cove as evidence of eutrophication. Buffalo Cove is typical of other areas in the lower basin. These stands are not only much more extensive than those seen in other basins of Louisiana known to be undergoing eutrophication, but the hyacinths are of the more robust, taller form typical of more strongly flowing water conditions.

These chronic stands of water hyacinth are reflective of the large nutrient input into the Atchafalaya River. The mean nutrient concentrations in the Atchafalaya River at Simmesport are 1.53 mg/l of total N and 0.18 mg/l of total P (USGS 1976). The combined mean concentrations of total N and P from Buffalo Cove, the mainstream, and Duck Lake/Flat Lake/Little Bayou Sorrel are 1.86 mg/l and .21 mg/l, respectively. These concentrations are high and comparable to other eutrophic areas in the coastal zone. The nutrient levels in the Buffalo Cove region may actually be higher than what is reflected by the concentrations in the water. The stands of hyacinth are able to assimilate nutrients and hold them within their biomass. Thus the concentrations of nutrients in the water at a given time are not always an adequate measure of whether the system is or will become eutrophic. The nutrients in flux through the system and stored in various components of the system besides the water must be considered. This is illustrated in Hutchinson's (1969) statement, "By a eutrophic system, I mean one in which the total potential concentration of nutrients is high; there may happen to be an extremely low concentration in the water because the supply at that moment is locked up somewhere else in the system--in sediments or in bodies of organisms...the stationary concentrations of the assimilable form of any nutrient thus will be of little interest in such a system; what is important is the total available supply in all forms and the rate at which it undergoes circulation." The high nutrient concentrations in the water at Buffalo Cove in addition to the extensive hyacinth stands points to hypereutrophic conditions in that area.

The flux of nutrients into the Atchafalaya Basin are high and show the importance of high water flow through the basin: 30,000 m tons P/yr and 264,000 m tons N/yr (obtained by multiplying the mean annual flow of the Atchafalaya, 1.42×10^{11} m^3/yr by the respective concentrations) (Garrett et al. 1969). The loading rate of phosphorus is 9 g P/m^2/yr (calculated by dividing the area of the lower basin, below I-10, by total nutrient flux). This is an extremely high loading rate. Therefore, both nutrient concentrations and loading rate indicate eutrophic conditions.

This is correlated with the extensive stands of water hyacinths mentioned and also with large pulses of undesirable blue-green algae in the mainstream of the basin (USGS 1976, Bryan 1975). Bryan notes that these pulses of <u>Anacystis</u> and <u>Anabaena</u> may be the first indicators of the environmental consequences of prolonged enrichment of swamp habitats.

Nutrient Sources

The nutrients in the Atchafalaya originate from several sources. The first is from within Louisiana via the Red River drainage. This river receives agricultural runoff and inputs from all major urban areas in North Louisiana (Alexandria, Shreveport, and Monroe). A second source is the Mississippi River. There are no inputs from Louisiana to the river north of Old River; thus, the nutrient levels reflect conditions outside of Louisiana. Finally there are local sources within the upper basin. For example, there are 147,000 acres of soybeans within the basin which obviously have some nutrient input. At this time it is impossible to separate the various input from these sources.

Water Quality

The high nutrient input into the basin results in deteriorating water quality. The large amount of organic matter introduced into the water from debris shed from water hyacinths creates a high biological oxygen demand. This is particularly extreme after winter dieback of the hyacinth. In warmer months this leads to widespread anoxic conditions and destruction of aquatic fauna. Freezes in January 1977 killed extensive areas of water hyacinth, leading to poor quality conditions in the spring and reduced harvests of fish and crawfish.

Conclusion

The nutrient concentrations, flux, and loading rates coupled with other trophic indicators, point to eutrophic conditions in the Atchafalaya Basin. This is not surprising because much of this water has nutrient input from northern Louisiana agriculture and municipalities and from a large area outside of Louisiana. There is additional local nutrient input. The large nutrient input results in extensive, chronic stands of water hyacinth which often result in high biological oxygen demand, anoxic conditions,and destruction of aquatic fauna.

CALCASIEU BASIN

The Calcasieu Basin lies within the Chenier Plain of southwestern Louisiana and drains an area of approximately 3,000 square miles (see Fig. 17). The headwaters of the Calcasieu River occur near Leesville in Vernon Parish, and the river flows in a southwesterly direction through Oakdale to the head of Calcasieu Lake near the border of Calcasieu and Cameron parishes. Several tributaries enter the Calcasieu River in the upland terrace area. Calcasieu Lake, covering an area of approximately 100 square miles, was originally part of the Calcasieu River and was formed by the growth of bars and beaches across the mouth of the river (Fisk 1948).

Nutrient Analysis

Johnson (1977) found several trends in the available water data for the Calcasieu Basin. Phosphorus appears in the saltwater areas of the Calcasieu River at higher levels than observed upstream. Nitrogen has higher concentration in freshwater areas. This may result from phosphorus retention and recycling by the sediments in the estuarine area. Phosphorus shows relatively high values in late summer (see Fig. 17) (Johnson 1977). Similar variations have been observed in Barataria Basin and may be due to pulses of detritus, relatively low river flow rates allowing more concentration of the element, and pulses from man-made sources such as agriculture.

Sources of Eutrophication

From calculated nutrient flux values, the total annual phosphorus flux into the study area by stream and river flow for 1976 is 236 metric tons from the upper basin. Both the high values of nutrient export peaks and their time of occurrence point to agricultural runoff as the source of the nutrient pulse. The high nutrient export values coincide with the months in which farmers in the area normally drain their rice fields after the application of fertilizers in order to apply herbicides (Johnson 1977). Another source of P is Lake Charles municipal waste, with an annual export of approximately 178 metric tons (3 lb of P/capita/yr, [Kemp and Mackenthun 1969]). Urban runoff for Lake Charles is estimated at 13 metric tons (90 g/capita/yr [Stern and Stern]). Approximately 20 percent of phosphorus and 40 percent of nitrogen input seems to be generated by industrial waste, but available data on industrial waste is so scarce that we are unable to estimate safely (Johnson 1977).

Phosphorus Loading into Calcasieu Lake

The total phosphorus loading for Calcasieu Lake was computed as follows:

Sewage	178 metric tons
Agriculture	236 metric tons
Urban runoff	13 metric tons
	427 metric tons

The total area of Calcasieu Lake 173 x $10^6 m^2$ (Barrett 1970) was divided into total phosphorus input giving a P loading of 2.5 $g/m^2/yr$. If industrial input is significant this number may actually be higher.

Water Quality

The high phosphorus loading of 2.5 $g/m^2/yr$ is indicative of eutrophic conditions in Calcasieu Lake and throughout much of the drainage basin. Other investigations by federal and state regulatory groups have shown deteriorating water quality in Calcasieu Lake and surrounding waters. Water quality standards are being violated for many parameters in the basin. Examination of water quality has shown that the application of secondary treatment and point source standards may be inadequate to obtain water quality objectives in much of the Calcasieu River Basin. Areas that are water quality limited are Mill Creek, the Calcasieu River from Oakdale to the saltwater barrier above Lake Charles, the Calcasieu River from the saltwater barrier to the Gulf, the Houston River to the Calcasieu River, and Bayou D'Inde (John Givens, La. Stream Control Commission, personal communication). The Calcasieu River has a low assimilative capacity for wastes due to its low flow rate. Its maximum flow is approximately 120,000 cubic feet per second, and under low flow conditions currents may actually reverse due to tidal influences. The Louisiana Stream Control Commission calculated the assimilative capacity of a portion of the Calcasieu River as compared to actual effluent (Kaiser 1976).

	Assimilative Capacity	Actual Effluent (Thousands of lbs/day)
Biochemical Oxygen Demand	7.5	59.3
Ammonia	2.8	35.5*

*Estimate for industry only.

This table includes only municipal sewage and industrial waste.

Conclusion

The P-loading rates, coupled with other data, point to eutrophic conditions throughout the entire Calcasieu Basin, from the upper Calcasieu Basin to the Gulf. The data also seems to indicate that the majority of nutrient input is agricultural in origin, and much of this is from fertilizer runoff. Municipal sewage from Lake Charles also introduces a substantial nutrient input. Insufficient data is available to calculate industrial waste input.

MANAGEMENT GUIDELINES

The coastal zone of Louisiana is rich in wetlands and water bodies and a major factor influencing the health of these estuarine systems is water quality. There are conflicting demands placed on our estuaries; they are extremely fertile areas, a vast source of fisheries, and major navigation areas and harbors. Because of this the estuaries attract large populations which use them as waste repositories. Although the coastal zone is a very resilient natural area, the effect of man is being felt. Water quality throughout large parts of the coastal zone is becoming seriously degraded; unless mitigation steps are taken, this can have far reaching effects on fisheries and quality of life in the coastal environment. This report is an analysis of available water quality data in such a way as to direct attention of decision-makers to points where their action can have rapid and significant ameliorative impact on the widespread and deleterious problem of eutrophication in the coastal zone.

Basin Concept

The fundamental concept when dealing with the problem of eutrophication is that the whole drainage basin must be considered rather than a single lake or bayou. Eugene Odum (1971) states this precisely:

"When man increases soil erosion or introduces quantities of organic material (sewage, industrial wastes) at rates that cannot be assimilated, the rapid accumulation of such materials may be destructive to the system. The phrase 'cultural eutrophication' (=cultural enrichment) is becoming widely used to denote organic pollution resulting from man's interests... The cause of and the solutions for water pollution are not to be found by looking only into the water; it is usually the bad management of the watershed that is destroying our water resources. The entire drainage or catchment basin must be considered as the management unit."

To control eutrophication, the influx of nutrients must be limited. Although there is concern over which nutrient sources should or can be controlled and by what methods, water quality improvement will never result if the continuous flux of nutrients is excessive (Uttormark et al. 1974).

Point and Nonpoint Sources

The categories point and nonpoint sources are important management concepts. A point source is a location at which nutrients are released in quantity and concentration compatible with practical means of nutrient removal. A diffuse, nonpoint source is an area from which nutrients are exported in a manner not compatible with practical means of nutrient removal. Municipal sewage effluent and industrial wastes are point sources, while urban-storm and agricultural runoff are diffuse sources (Uttormark et al. 1974).

<u>Overland Flow for Point Source Treatment</u>

Point sources such as municipal sewage can be alleviated by proper treatment. However, secondary waste treatment does not rid the water of nutrients; and tertiary treatment, which does, is prohibitively expensive. Fortunately, the marshes themselves can act as tertiary treatment using the overland flow method. If water from sewage, agriculture, an urban runoff were allowed to flow slowly through wetlands, the productivity of the swamp and marsh could be increased and nutrients absorbed by the soil-plant system. Meo (1974) measured a phosphorus removal rate by the soil-plant system during overland flow treatment of 4.73 g/m^2. Plant productivity of the area treated was increased by 50 percent (see also Meo et al. 1975, Turner et al. 1976). In Barataria Basin, for example, in Area I, 5.9×10^4 of marshlands (14.57 acres or 7 percent of marsh in Area I) would be required for overland flow treatment to remove phosphorus now being put in to that area. If this were done, the productivity of the marsh could be potentially increased by 7.2 percent. In Area II, $7.2 \times 10^7 m^2$ of marshlands (17,784 acres or 8 percent of total marsh in Area II) would be required for overland flow treatment to remove phosphorus; the productivity of the marsh could be potentially increased by about 6.4 percent. (This approach is applicable for the other hydrologic basins as well.)

An equivalent value of marsh treatment can be obtained by comparison with present tertiary treatment costs. Tertiary treatment can remove from 0.03-0.30 mg/l of P from municipal wastewater, but the costs are very high. For a 1 MGD treatment plant, tertiary treatment costs between $0.42-$1.23/1000 gallons P removal. For overland flow, the cost is about $0.17/1000 gallons treated. For wastewater with an average concentration of 7.5 mg P/l, the savings for P removal using overland flow is about $0.9-$3.8/g P. Removal of P presently put into Barataria Basin using present tertiary technology would cost between 5.6 and 23.6 million dollars per year more than overland flow.

Nonpoint Source Techniques

For diffuse, nonpoint sources, nutrient abatement depends on techniques to prevent excessive nutrients from directly entering water bodies. Runoff from mismanaged lands such as agricultural areas, highway construction, and suburban areas inputs excessive levels of nutrient due to sediment erosion and, in the case of agriculture, fertilizers.

Agricultural Management Suggestions

Hinchee (unpublished) has suggested several solutions to lessen the problem associated with agricultural runoff. One suggestion is to promote sheet flow of runoff water across swamps and marshes or, in other words, use overland flow treatment. Another is to limit fertilizer application. This could have a considerable effect, since according to Golden and Ricaud (1963, cited by Hinchee, unpublished) sugarcane production would drop only 17.6 percent if no fertilizers were added. Figure 18 demonstrates this clearly. Currently, a farmer figures his rate of fertilizer application according to return on his investment.

It may be that the ecological damage done by the addition of fertilizers to sugarcane exceeds the value of slightly increased yield.

If fertilizers are to be used, they should be used as sparingly as possible. Work done by Jones and Zwerman (1972) showed that the level of nitrogen in agricultural runoff was proportional to the amount of nitrogen fertilizer added (Hinchee, unpublished).

The timing of fertilizer application is critical. If fertilizer is applied at times of maximum uptake, runoff is limited (Fig. 19). Figure 19 shows uptake rates over time for nutrients in sugarcane. It shows clearly that maximum uptake occurs in June through August, therefore this is the optimal time for fertilizer application. The practice of fall and winter fertilizing is a definite cause of loss of fertilizers from fields at the expense of the farmer and the natural system (Hinchee, unpublished).

Water management can also be used to minimize nutrient runoff. Gambrell, Gilliam, and Weed (1974) suggest that by maintaining a high water table, denitrification is increased, minimizing runoff. A study done by the Department of Agronomy, College of Agriculture and Life Sciences, Cornell University (1971) showed that phosphorus runoff was proportional to the quantity of runoff water more so than to the phosphorus added. This would indicate that minimizing runoff would lower nutrient loss to natural waters. Both of these could be applied to sugarcane which is heavily drained. Some of this draining is necessary for growth, especially in late winter (Breaux, et al. 1972). However, it may be possible to limit runoff at other times. It may also be possible to allow rice runoff to dry off, decreasing phosphorus loss.

The type of fertilizer may be important. The study done by the Cornell Department of Agronomy and Life Sciences states that the use of manure significantly reduces nutrient runoff. This is a practice which could also solve some animal waste disposal problems.

The method of application of fertilizer may also be important. Calvert and Phung (1971) and Calvert (1975) have shown that in citrus groves deeper tilling reduced both nitrogen and phosphorus runoff by 53-74 percent and 76-86 percent, respectively. It was also shown that adding lime to the soil could reduce runoff.

It should be realized that all of these methods were worked out in areas other than coastal Louisiana and may not all be applicable. Research in these areas in Louisiana is badly needed. Extension agents and other government farm advisors need to be more aware of this problem. Fall and winter fertilization is an example of what appears to be bad advice given to farmers.

Below is a list of guidelines. It is realized that these are a first attempt and need future modification.

1. Reduce fertilizer use to lower levels, or where possible, eliminate fertilizer use.

2. Time fertilizer application to correspond to times of maximum uptake, eliminate fall and winter fertilizing.

3. Reduce the drainage of fields, allow the soils to remain wet to promote denitrification and evaporation.

4. Use manure to condition soil and to replace chemical fertilizers.

5. Plow fertilizer as deeply into the soil as possible.

(Hinchee, unpublished).

Management for Urban Runoff

Urban runoff, a nonpoint source, must be controlled from the standpoint of reducing nutrients entering the waters. (There is still the problem of toxins and heavy metals input into receiving waters.) Urban erosion from road construction and urban-suburban development supplies significant amounts of sediment even though total acreage under construction may be low (Uttormark et al. 1974). Efforts should be made by highway departments and developers to reduce this to a minimum.

Other sources of nutrient input is from lawn fertilizers, animal population, and leaves. Lawns often require nitrogen, but generally there is no need for additional phosphorus. The use of fertilizers with little or no phosphorus could be encouraged. Leachate from leaves has an input into receiving waters, but much of this could be prevented by not burning or storing leaves in storm gutters (Uttormark et al. 1974).

Canals and Eutrophication

Canals are an important factor accelerating the eutrophication process by shunting nutrient-laden water from agricultural and urban areas directly into water bodies. Water movement through a hydrologic basin is characteristically sluggish, and the nutrients can be taken up by wetland vegetation. The canals "short circuit" this flow of water and consequently the level of nutrients in the water increases until blooms of 'weed' plants such as water hyacinth choke waterways and lakes and produce conditions for massive fish kill. Canals also serve as conduits for saltwater intrusion which is tied to the problem of land loss. Salinity intrusion into fresh areas via canals often kills the marsh causing it to break up and form ponds. Saltwater intrusion is also causing a shift in the nursery ground to the north where the fisheries could feel the brunt of eutrophication. Prevention of saltwater intrusion may not be possible but may be lessened by limiting the number of canals that extend through the various marsh types.

Determination of Trophic Status

To determine the trophic status of water bodies several techniques can be utilized. Ideally, nutrient loadings would be determined by direct measurements and definite sources and contributions pointed out. The costs of doing this is almost prohibitive and less costly methods have been developed for use in assessing management alternatives and establishing priorities (Uttormark et al. 1974). Nutrient loading, specifically phosphorus loading, is such a technique. The amount of phosphorus input from various sources such as municipal sewage, agricultural runoff, urban runoff, and industrial waste can be quantified. With this information and the size of the lake, phosphorus loading can be calculated. It is important, however, that the P-loading be done in correlation with other trophic indicators such as nutrient concentrations, hydrology, and biological indicators. Because the lakes and bayous in Louisiana are naturally high in nutrients, it may be that the critical loading level of P is higher than 0.4 $g/m^2/yr$ and actually closer to 0.8-1.0 $g/m^2/yr$).

The application of P-retention index (Kirchner and Dillion 1975) must include an appreciation of the complex internal nutrient cycles in the lake sediments, the condition of the sediments (aerobic or anaerobic), history of nutrient loading, depth of water in lake, etc.

To determine the trophic status of a water body using the trophic state index, certain standardized parameters must be taken (total phosphorus, total organic nitrogen, secchi depth, chlorophyll a, ammonium, dissolved oxygen) and analyzed by methods presented in Strickland and Parsons (1968). It is important that the water quality collected by the different agencies throughout the state be consistent in parameters and analytical methods. In some areas in the coastal zone, such as White Lake and Grand Lake, there is very insufficient data available. As the trophic state index for the estuaries of Louisiana becomes completed, it will be correlated with phosphorus loading and biological indices.

Conclusions

1) Eutrophication is a widespread problem throughout the coastal zone of Louisiana. It leads to poor water quality, development of nuisance algal blooms, decline in desirable commercial and sports fishery species, and diminished recreational usefulness of water bodies.
2) The major cultural sources of nutrients leading to eutrophication are urban runoff, domestic sewage, and agricultural runoff.
3) Eutrophication can be controlled and is reversible. If direct introduction of nutrient-laden water into aquatic bodies is eliminated, the water bodies will eventually return to a less eutrophic state. The length of time for this to take place depends on the duration and intensity of historical nutrient input. We believe that land treatment in wetlands (overland flow) offers a viable means of treatment of nutrient wastes.

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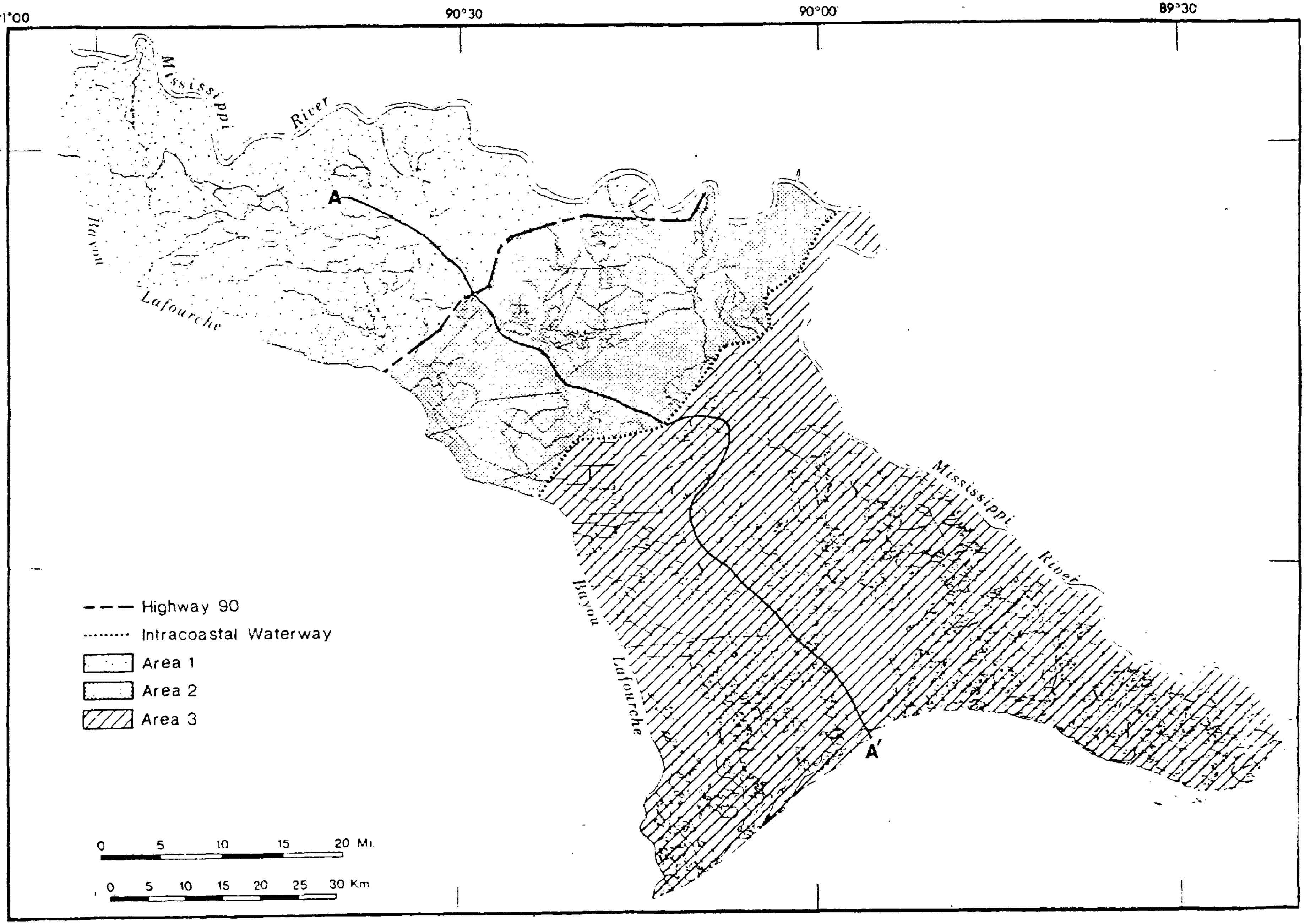

Fig. 1. Barataria Basin's three areal divisions.

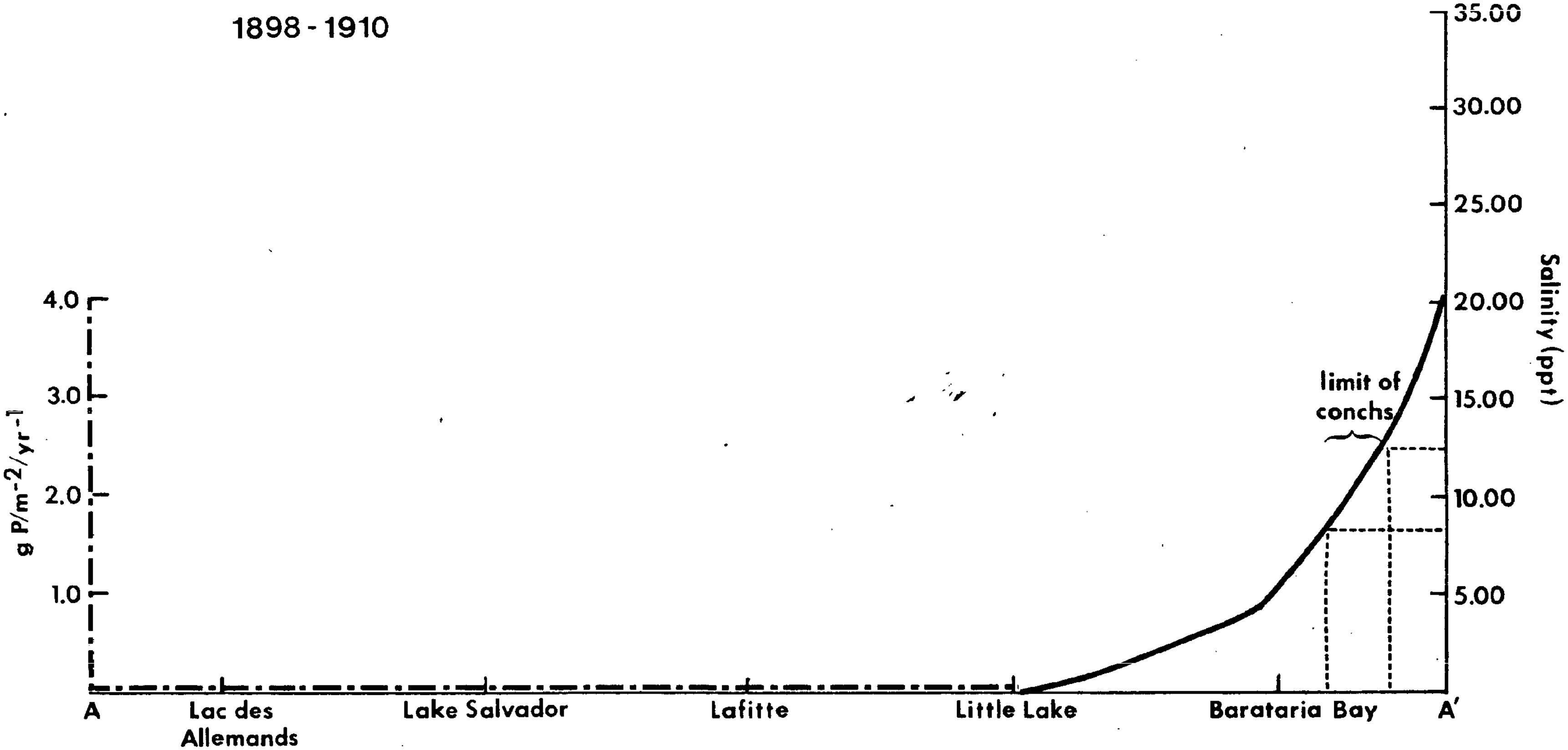

Fig. 2. Estimated phosphorus-loading rate ($g/m^2/yr$) and salinity levels (ppt) at various locations in Barataria Basin, 1898-1910. Conch range illustrates southern limit of oyster production.

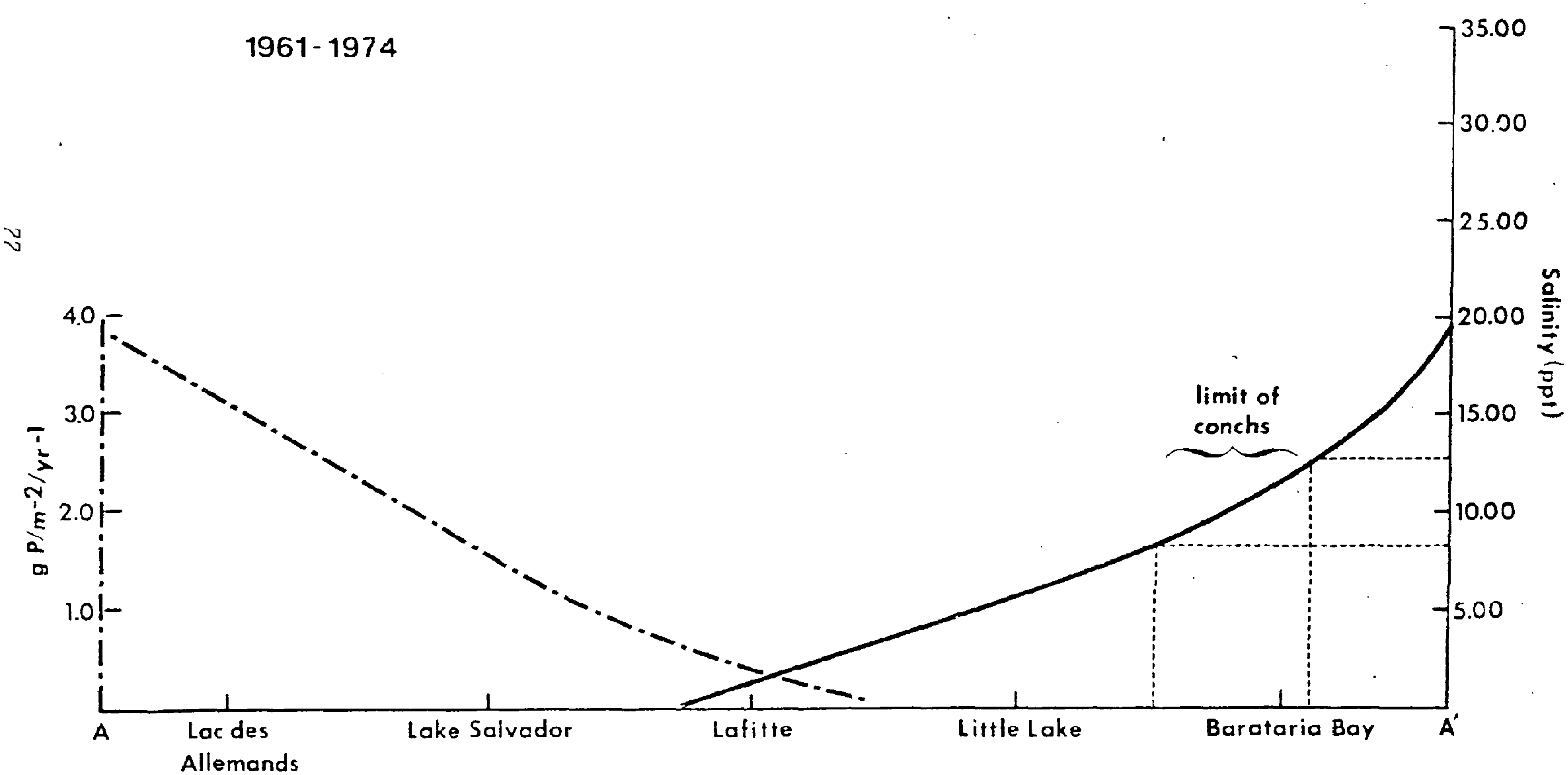

Fig. 3. Phosphorus-loading rate ($g/m^2/yr$) and salinity levels (ppt) at various locations in Barataria Basin, 1961-1974. Conch range illustrates southern limit of oyster production.

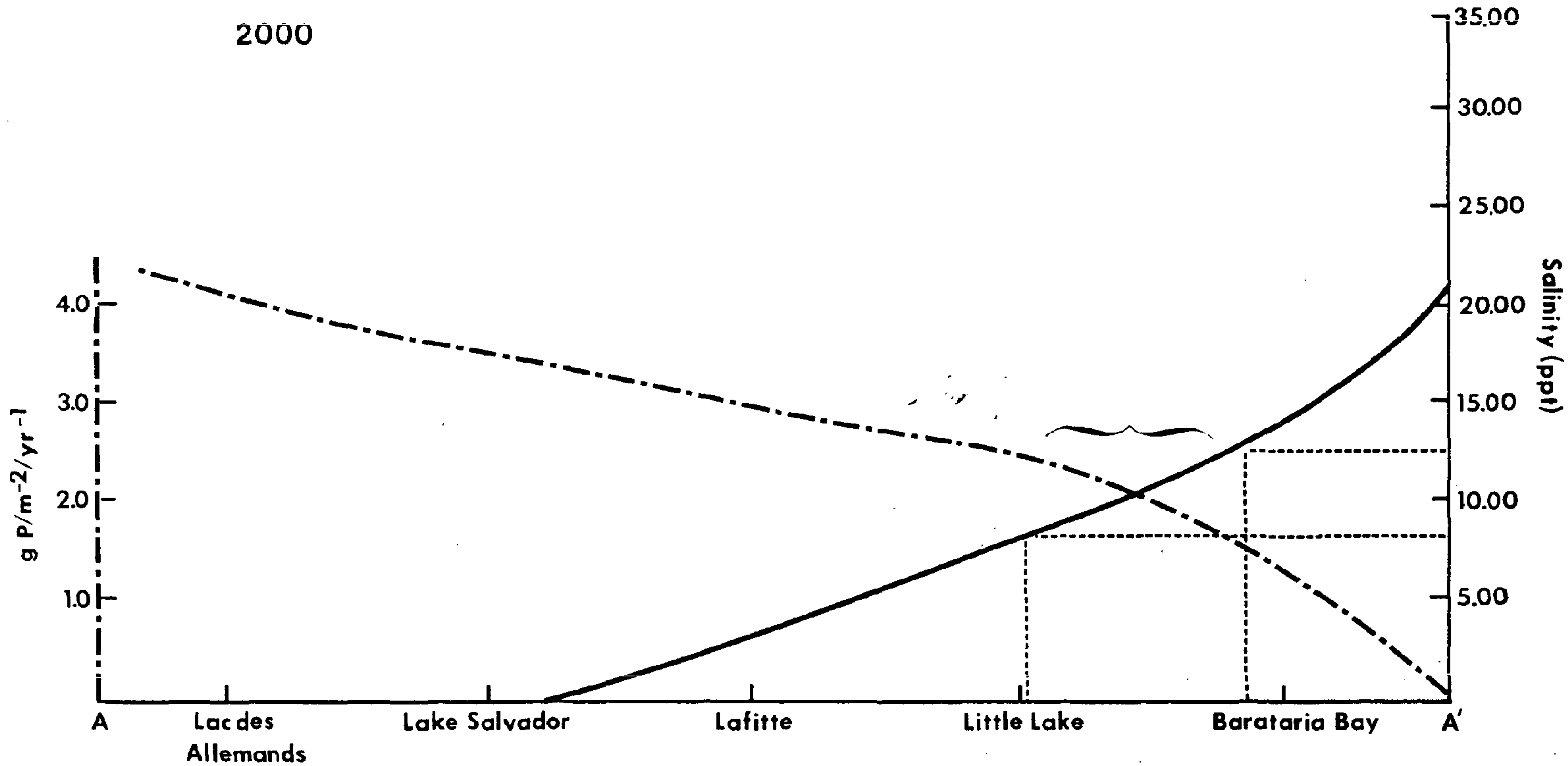

Fig. 4. Estimated phosphorus-loading rate (g/m^2/yr) and salinity levels (ppt) at various locations in Barataria Basin for year 2000. Conch range illustrates southern limit of oyster production.

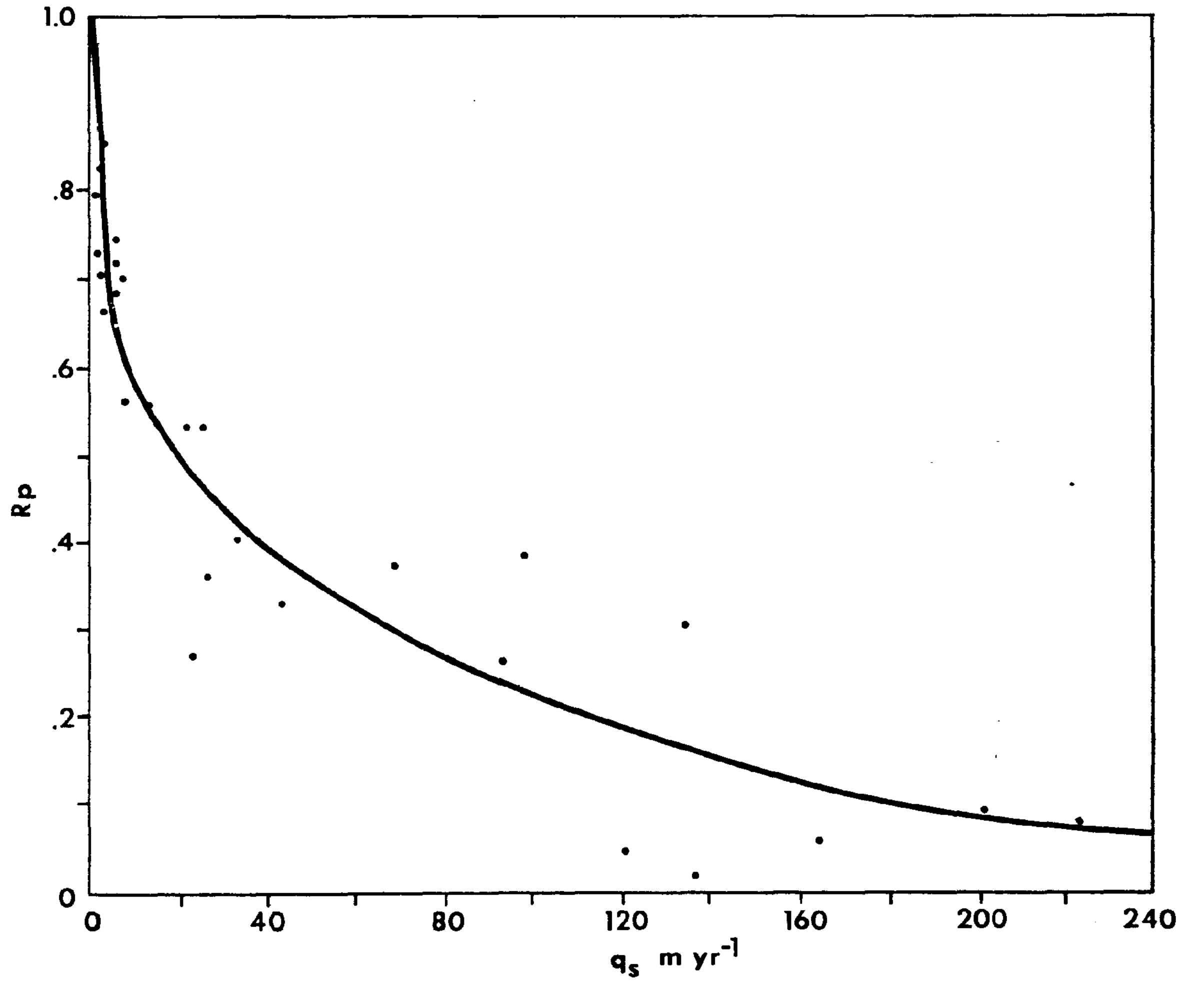

Fig. 5. The relationship between the areal water load (qs) and phosphorus retention (Rp) in fifteen southern Ontario lakes.

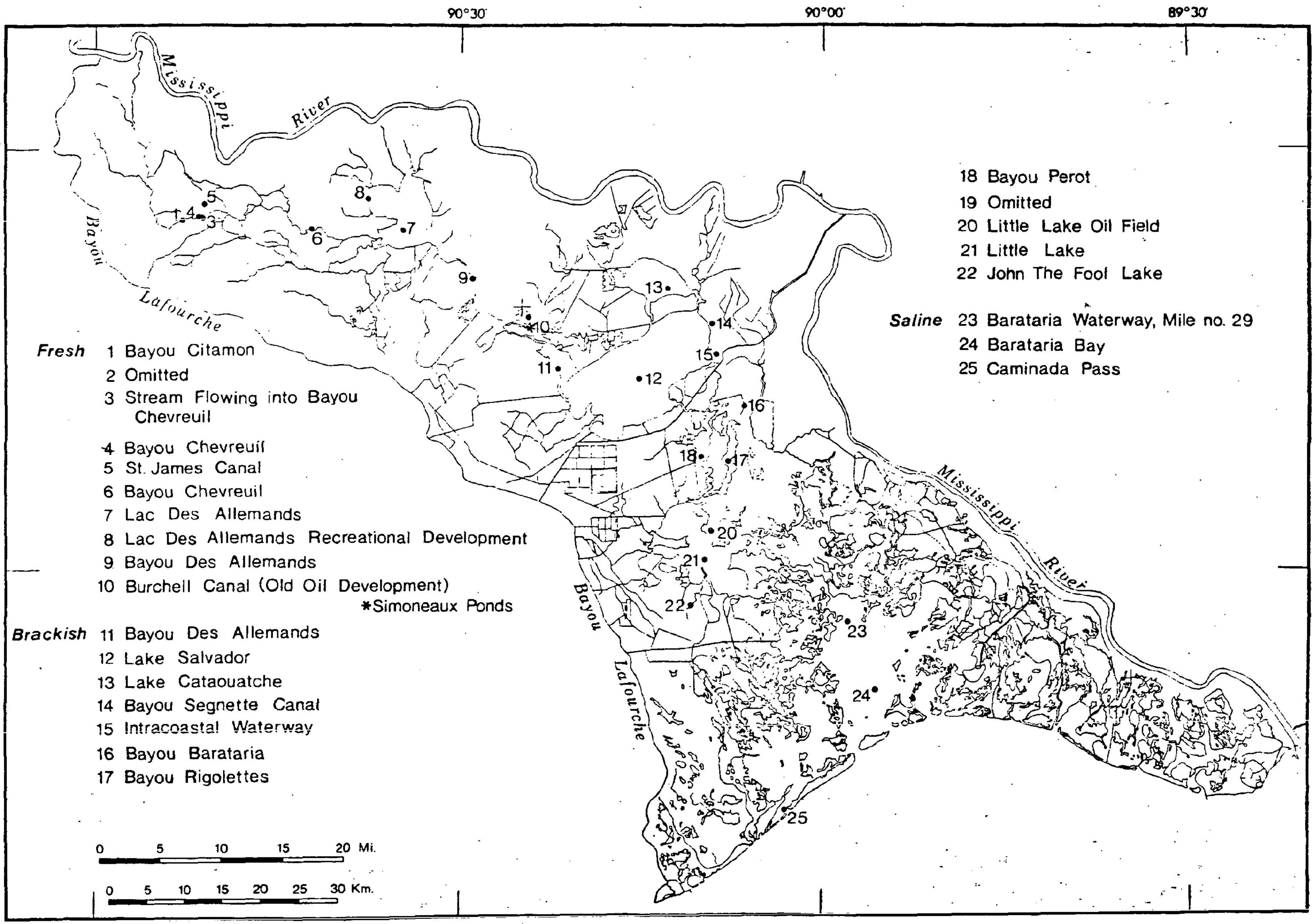

Fig. 6. Location of the 23 water-quality stations in Barataria Basin.

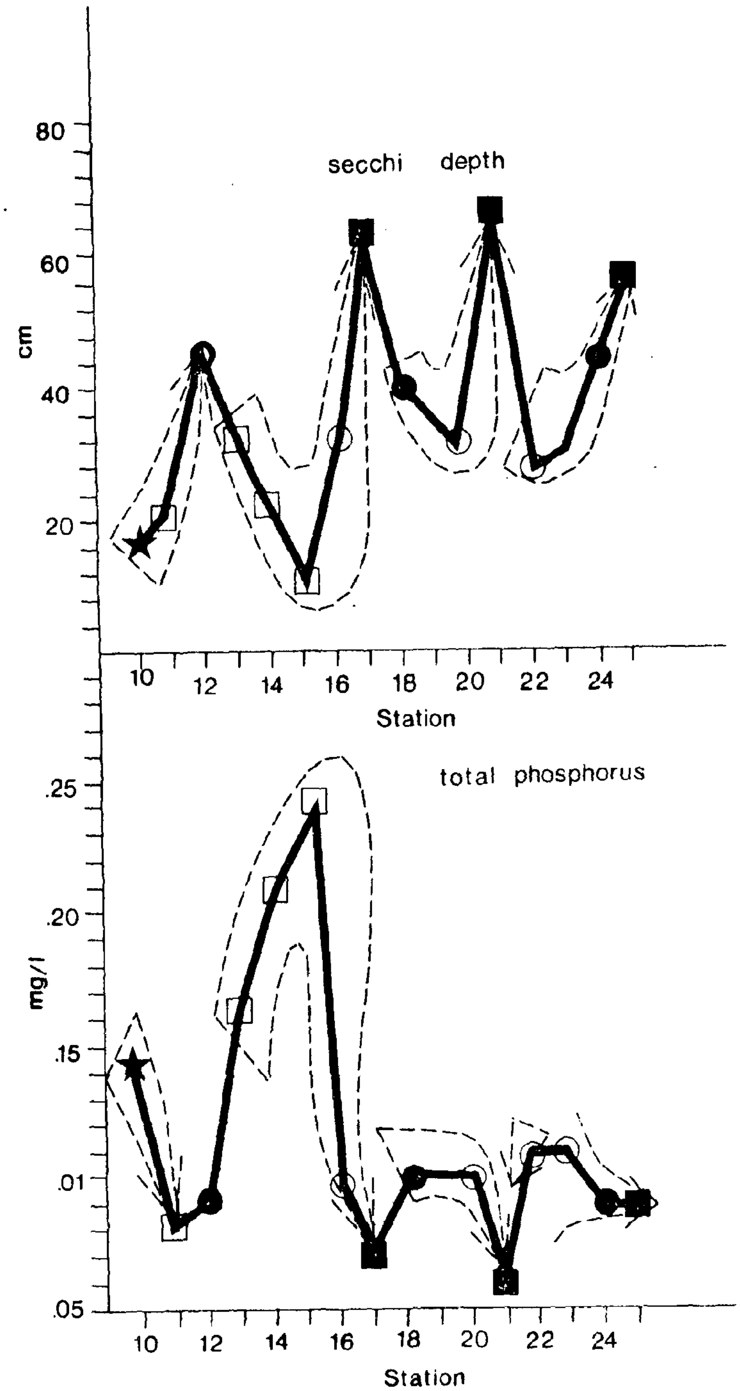

Fig. 7. Secchi depth (top) and phosphorus concentrations (bottom) at various brackish and saline stations in the Barataria Basin. See text for discussion. Solid squares and circles are clean water stations (group 2, Fig. 9). Open squares and stars are eutrophic stations (group 3b, Fig. 9).

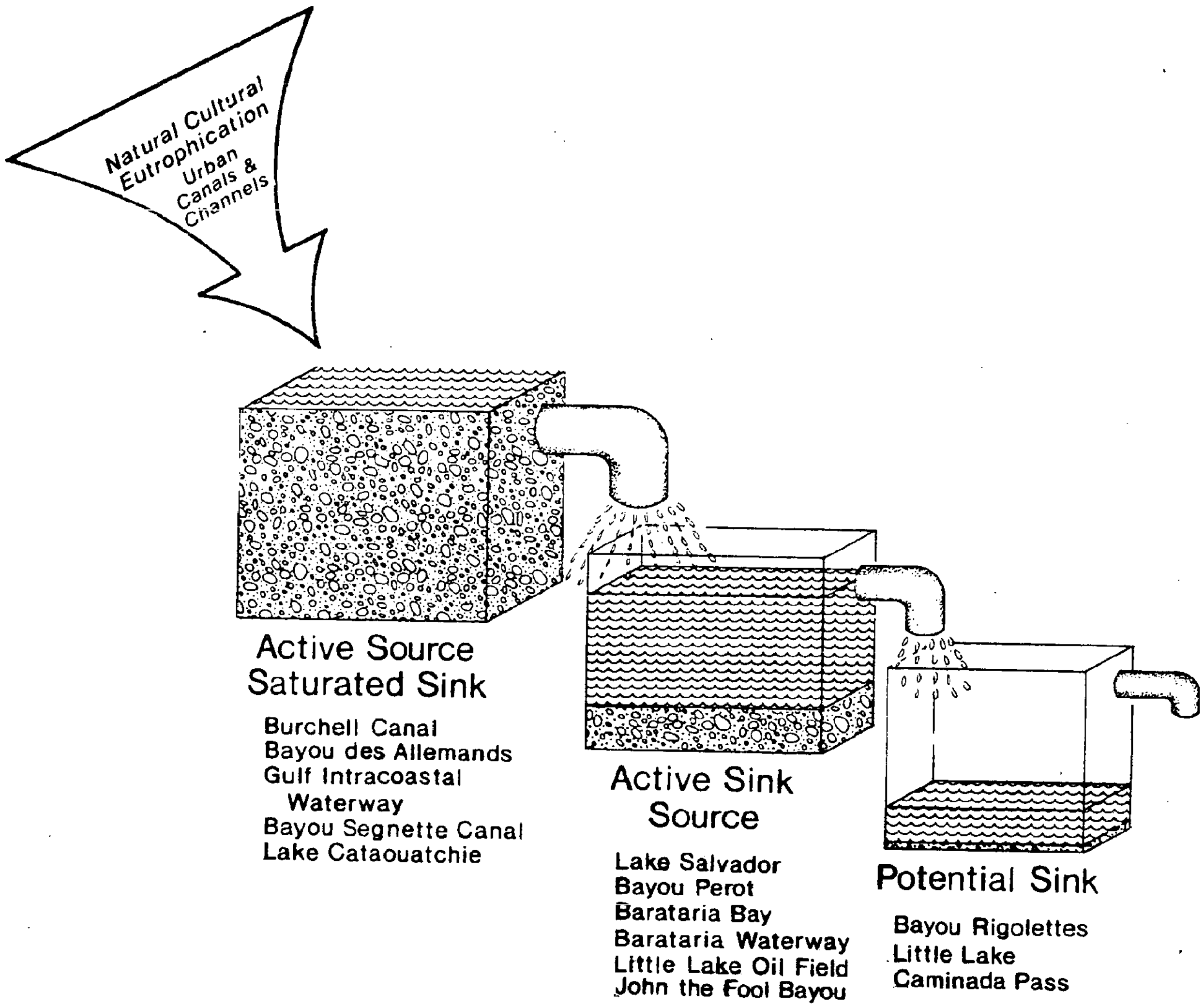

Fig. 8. Schematic classification of brackish and saline stations in the Barataria Basin according to water quality.

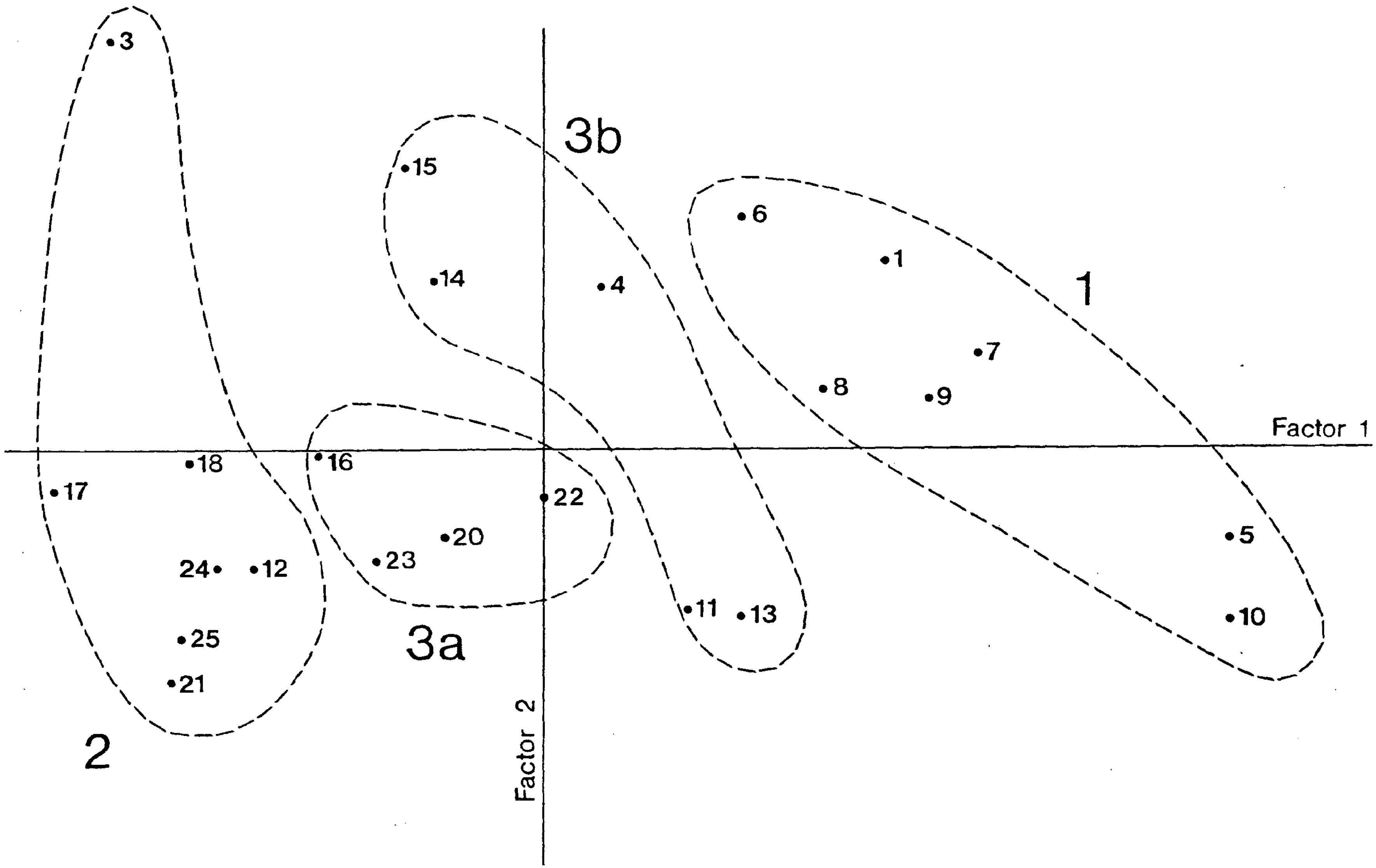

Fig. 9. Graphic representation of the results of factor analysis and cluster analysis. Dashed lines enclose cluster groupings.

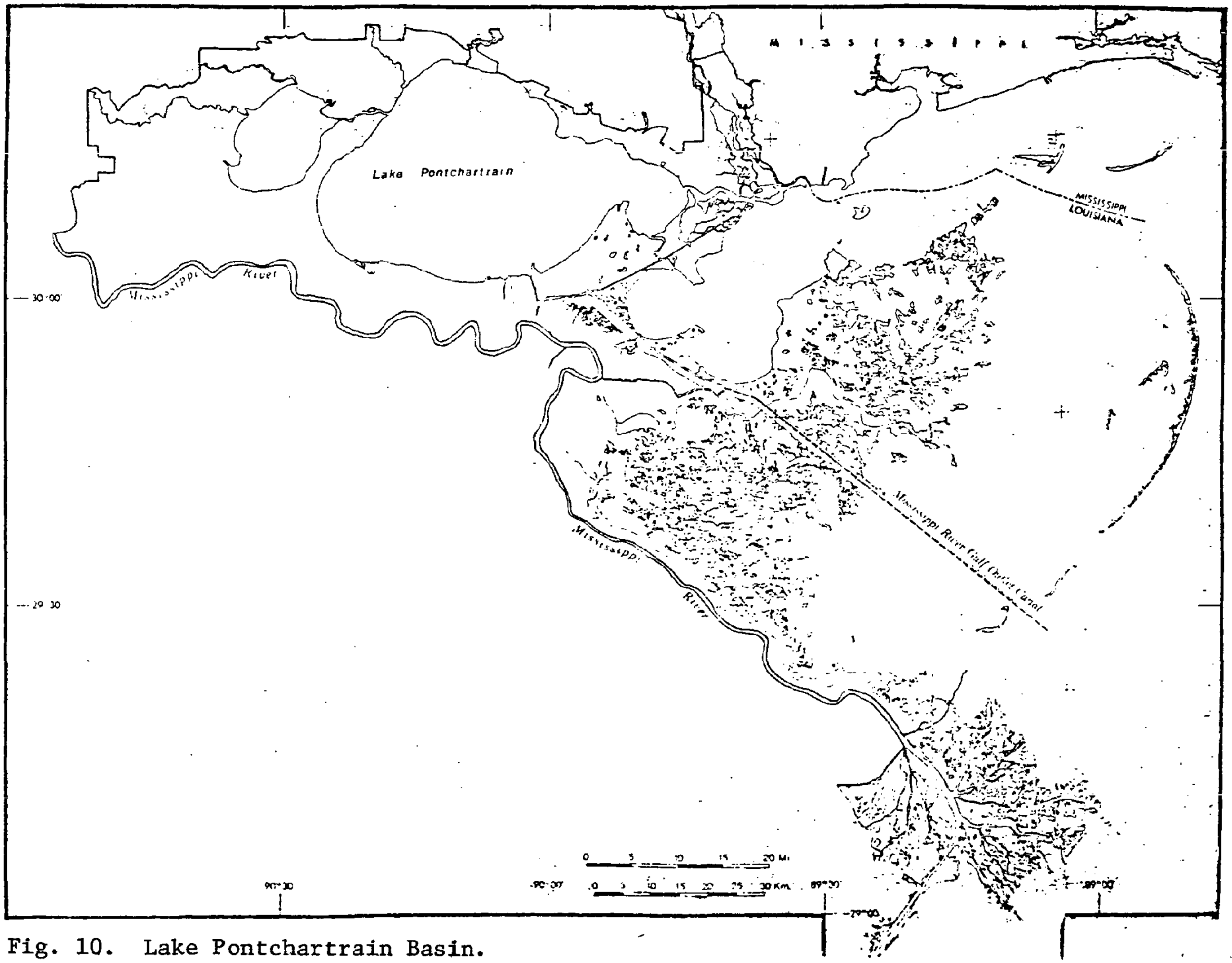

Fig. 10. Lake Pontchartrain Basin.

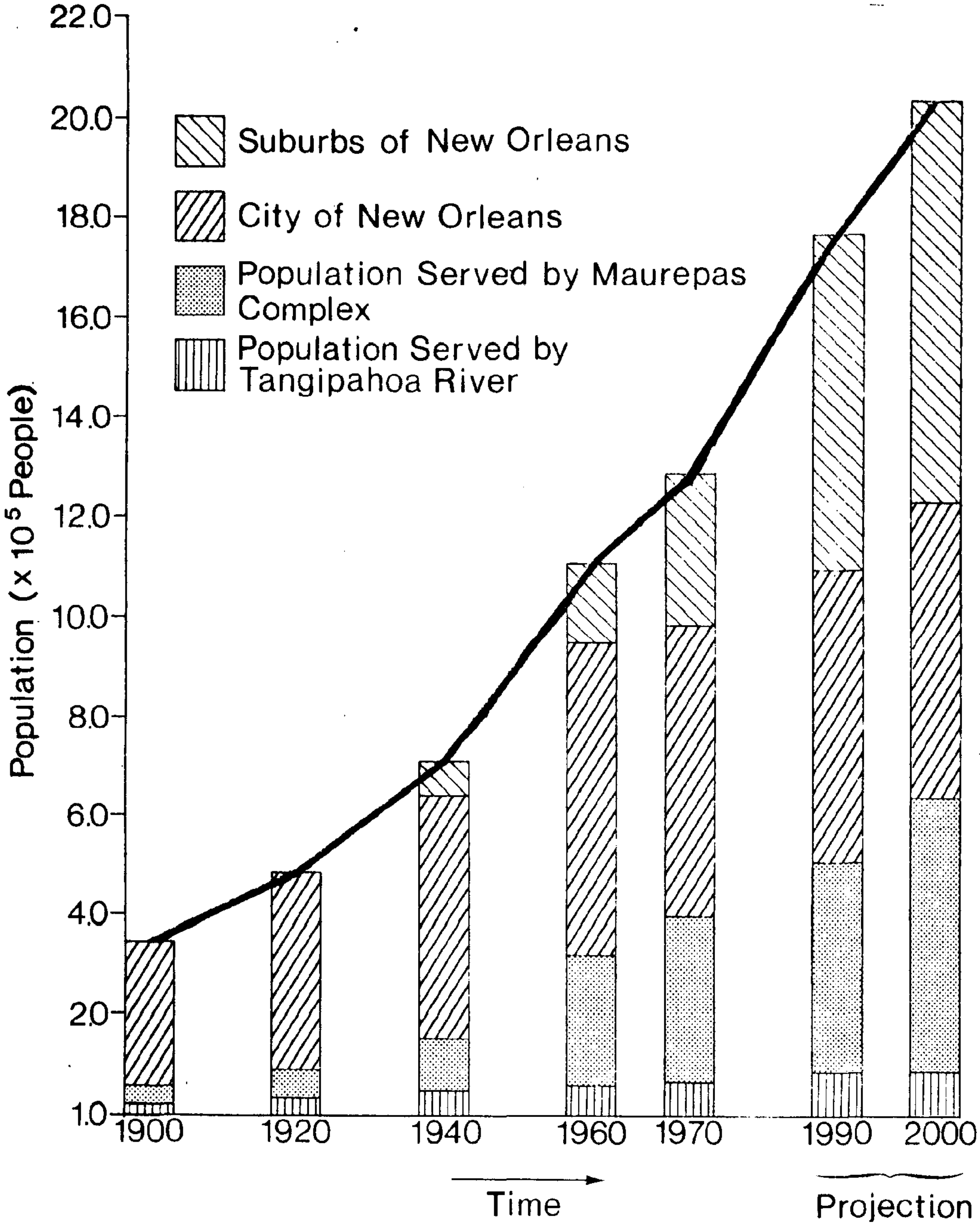

Fig. 11. Population growth in Lake Pontchartrain drainage area.

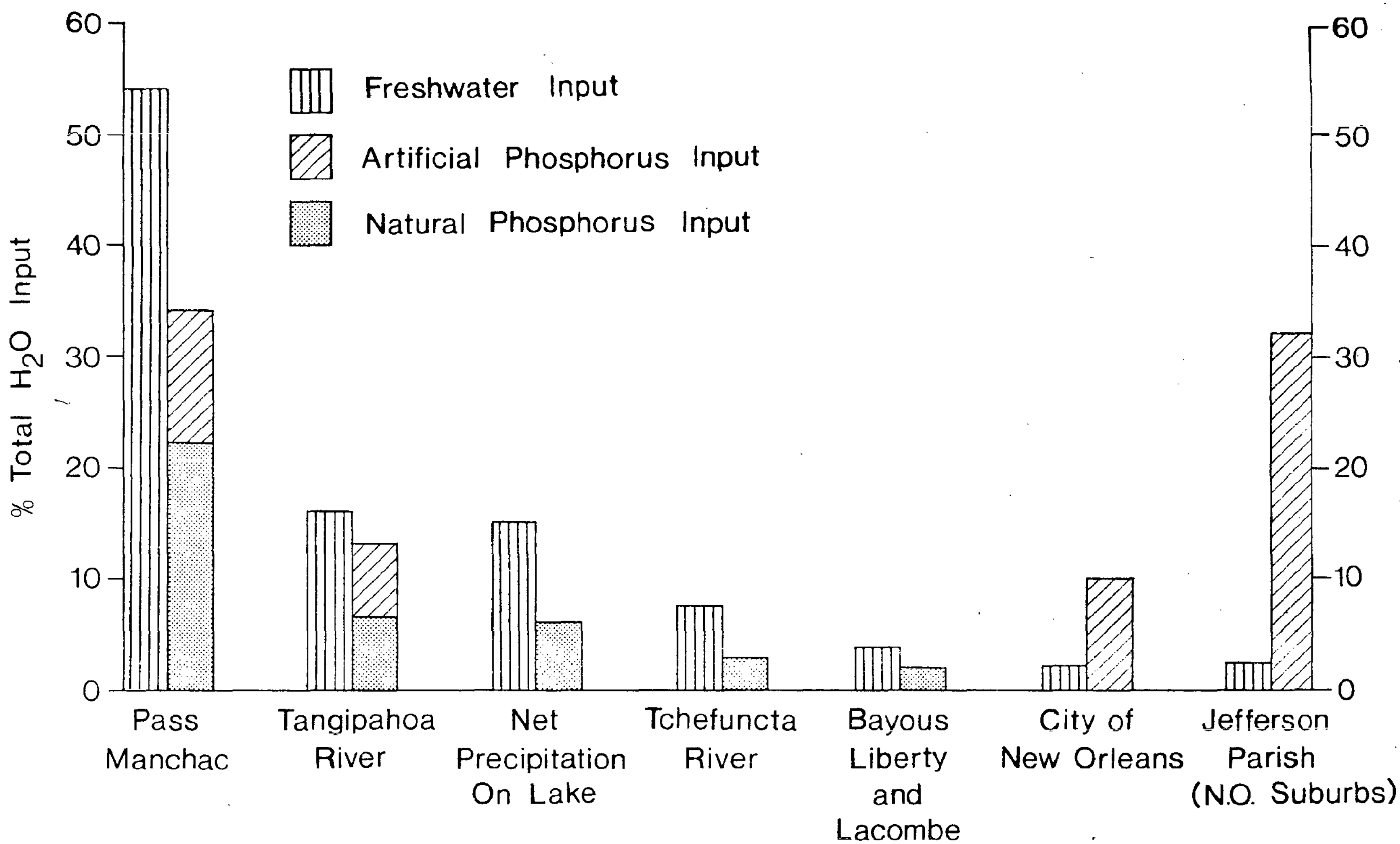

Fig. 12. Major freshwater and phosphorus sources of Lake Pontchartrain.

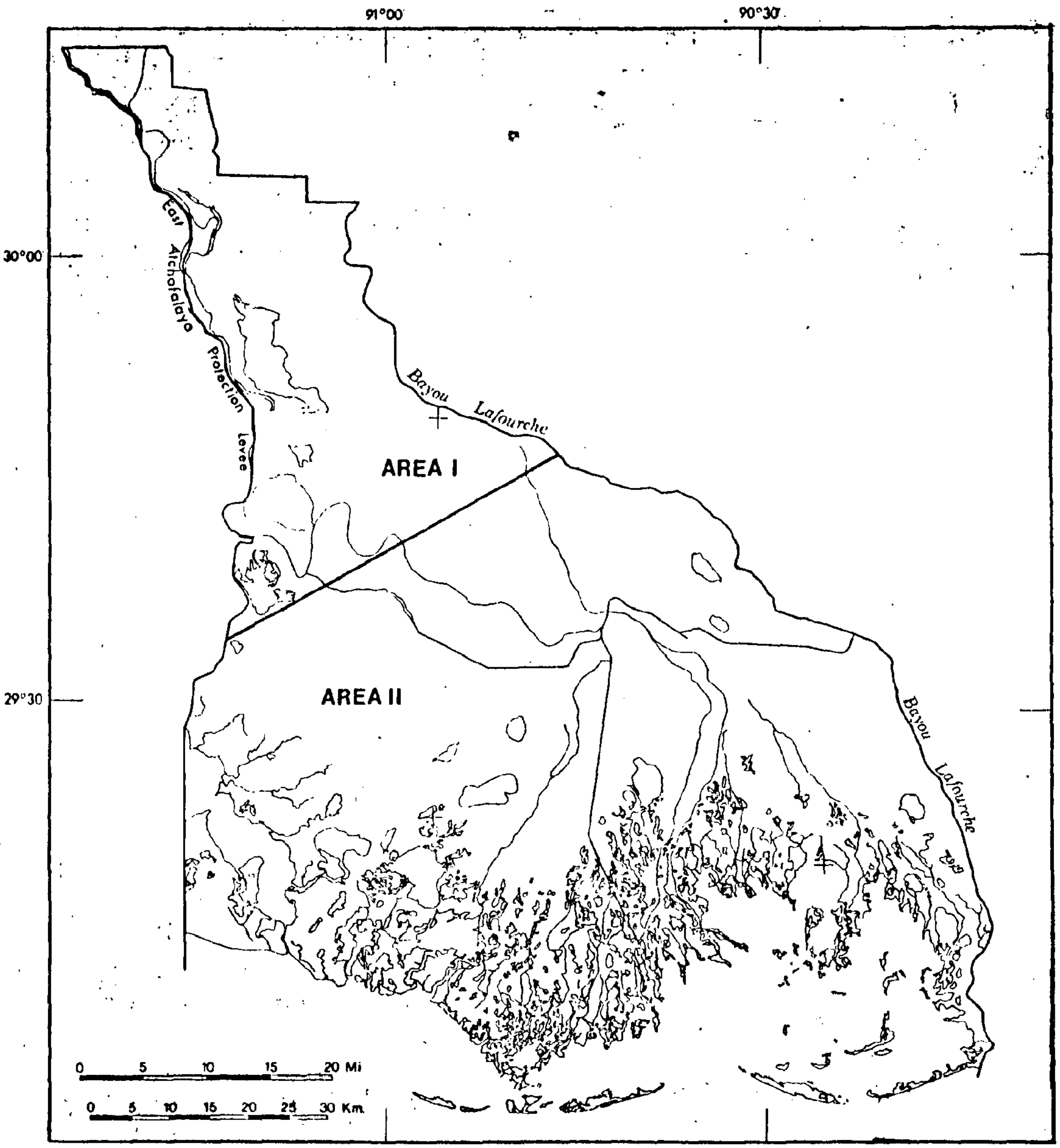

Fig. 13. Terrebonne Basin: Area I and Area II.

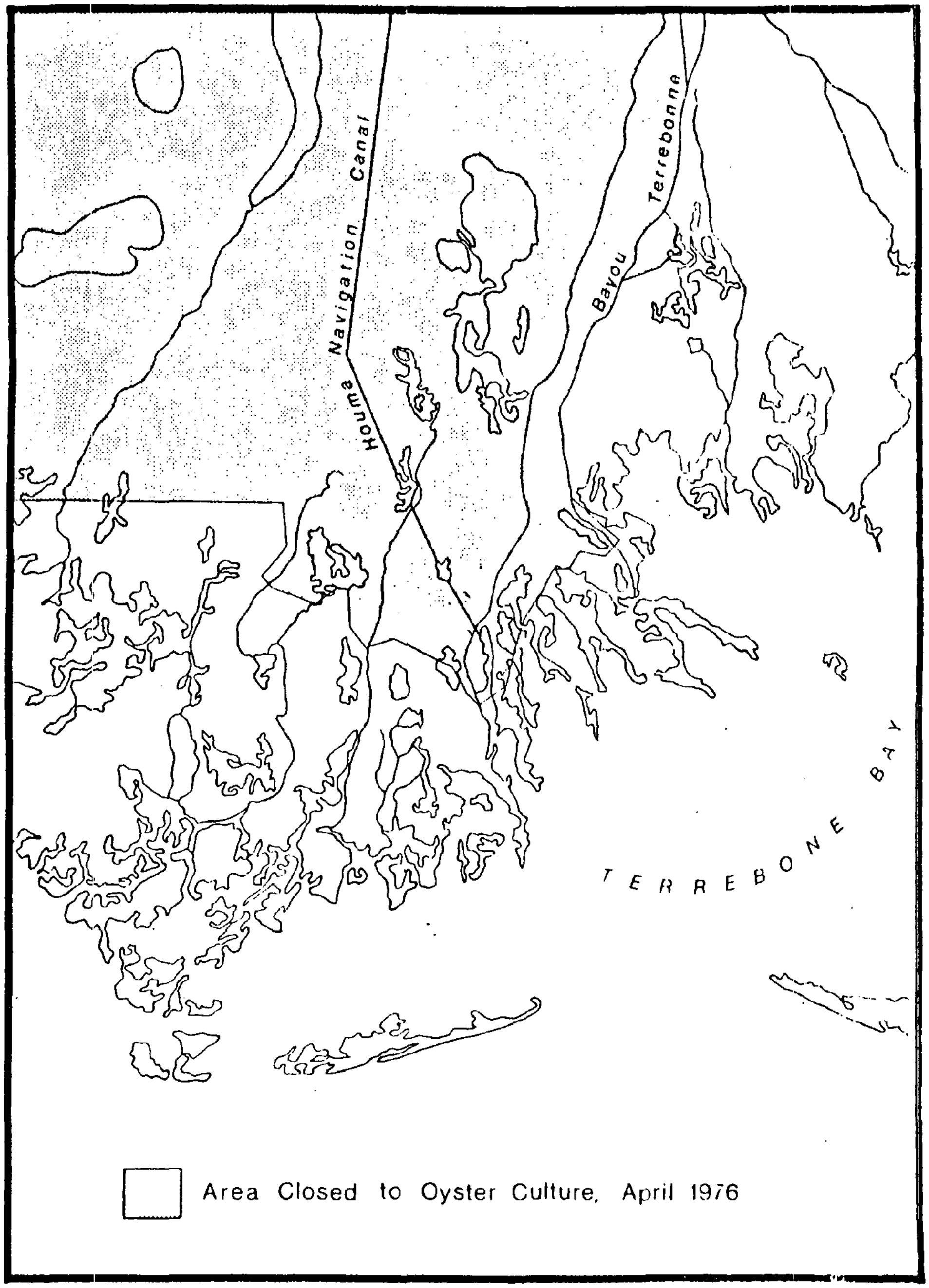

Fig. 14. Current closure of oyster grounds in Terrebonne Basin.

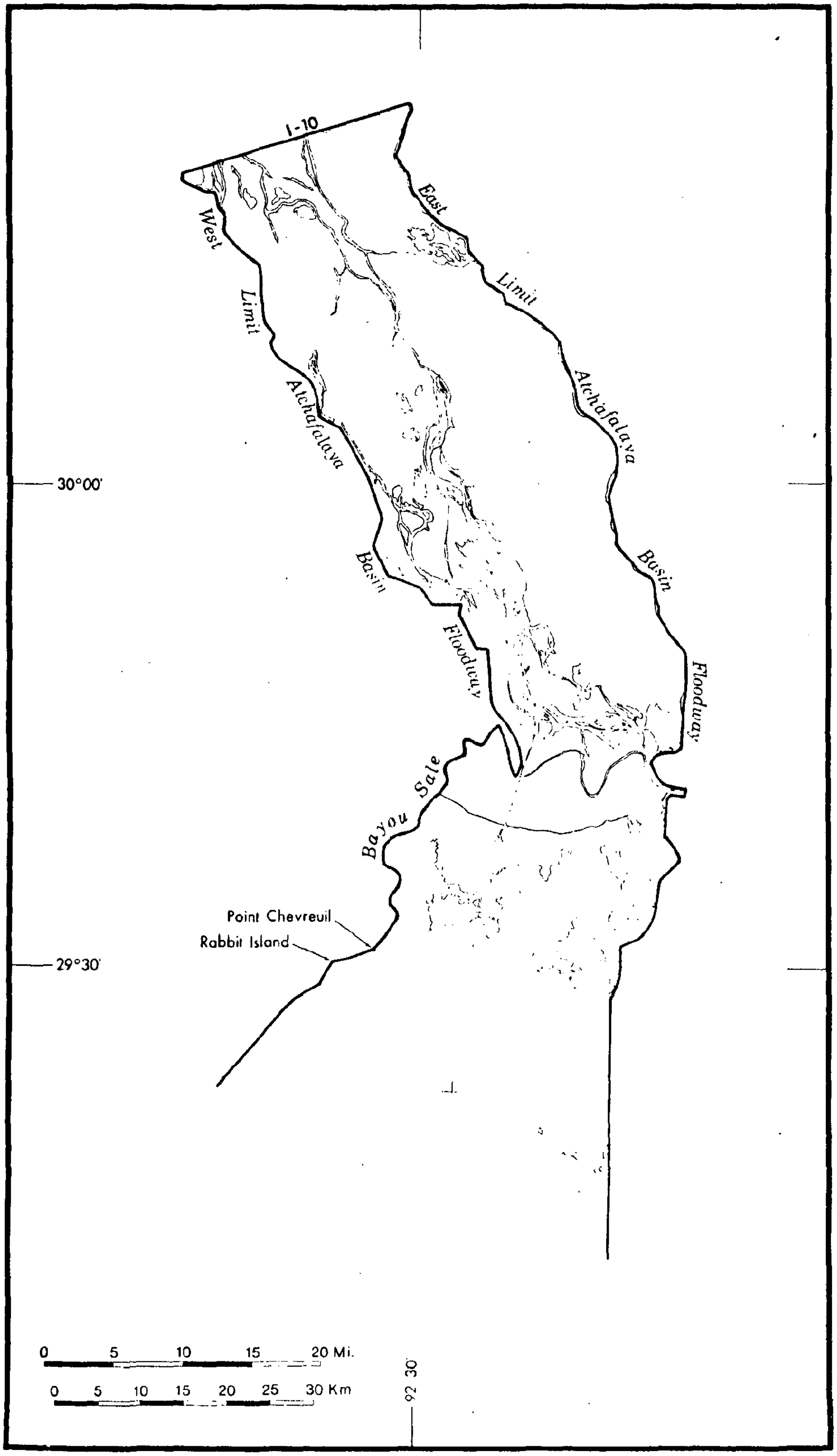

Fig. 15. Atchafalaya Basin.

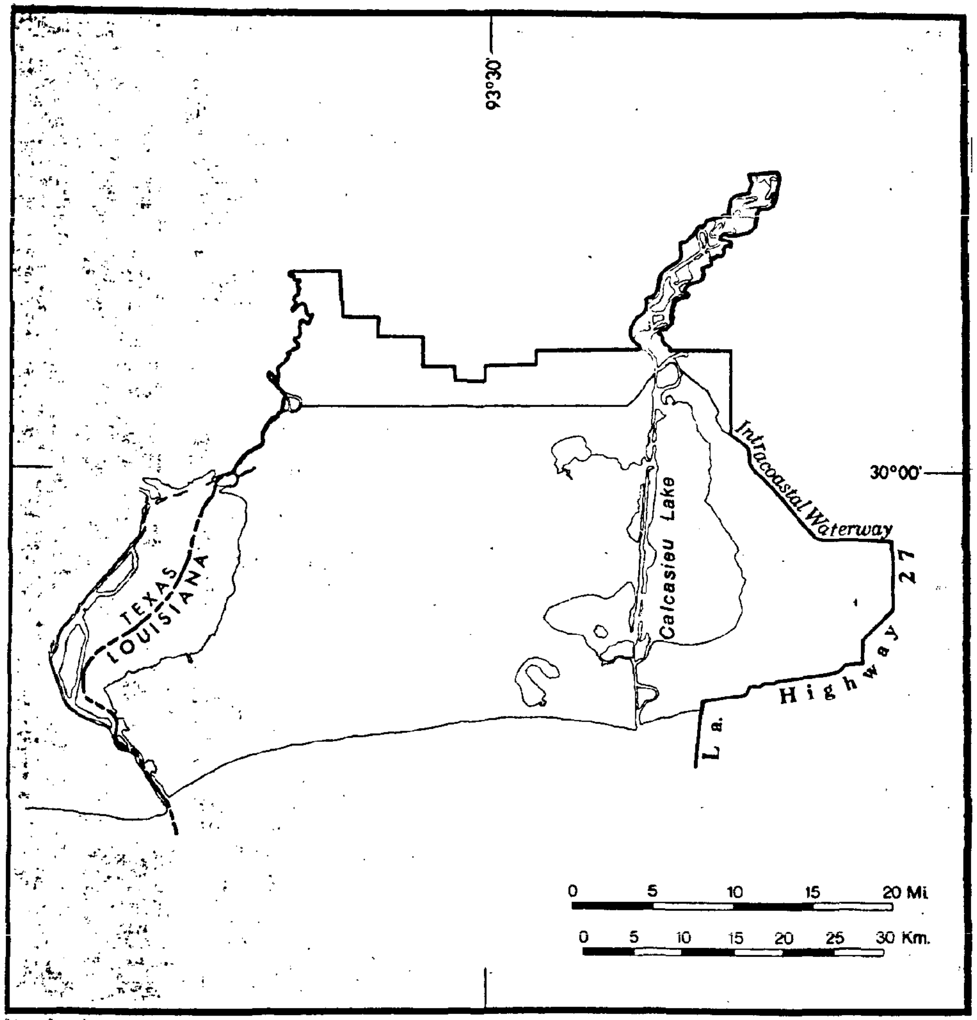

Fig. 16. Calcasieu Basin.

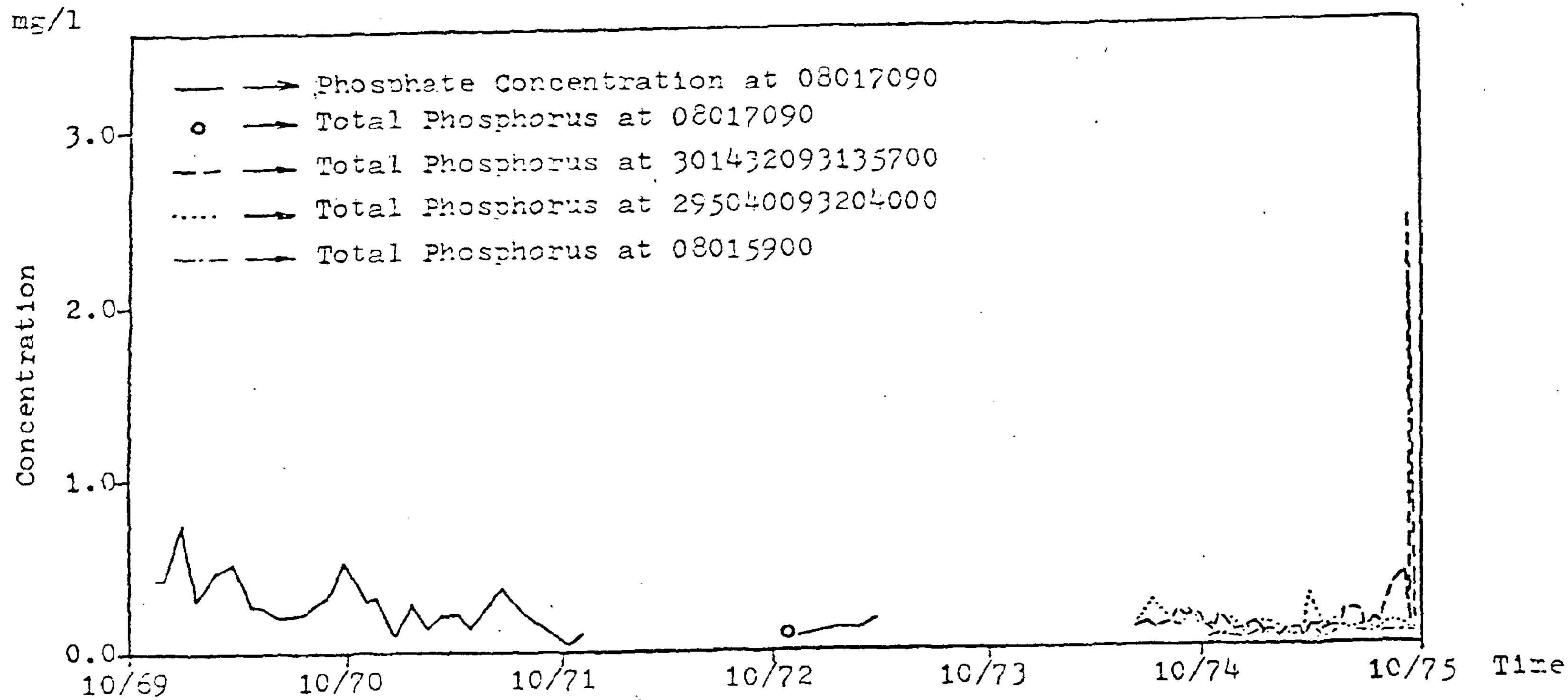

Fig. 17. The variation in phosphate concentration at one station (Burton Landing) on the Calcasieu River and the variation in total phosphorus concentration at this and three additional stations along the river. Data is graphed for the water years 1970–1975. Note that total phosphorus is measured on a phosphorus basis, whereas the phosphate concentration is graphed on a phosphate basis. There appear to be relatively high values of P during late summer, perhaps largely due to the low river-flow rates at that time (Johnson 1977).

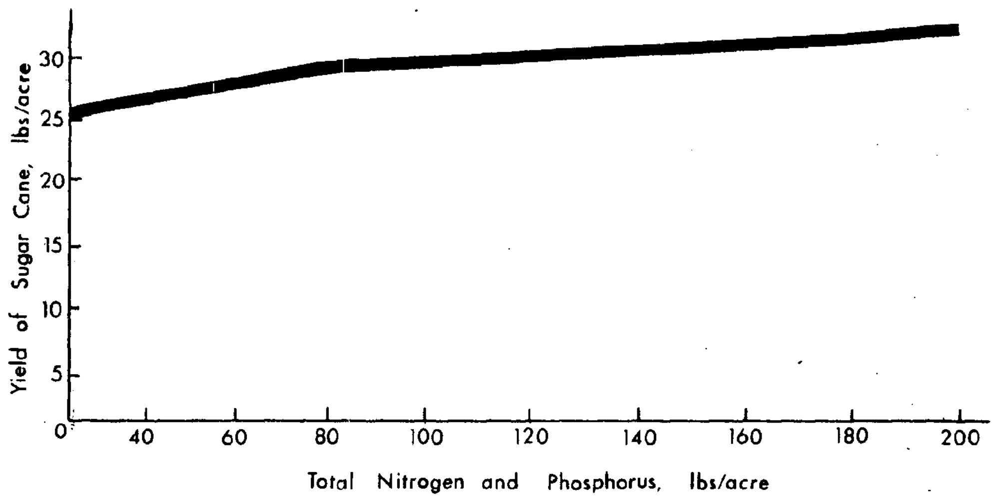

Fig. 18. Yield of sugarcane (lbs/acre) compared to amount of total nitrogen and phosphorus added (lbs/acre).

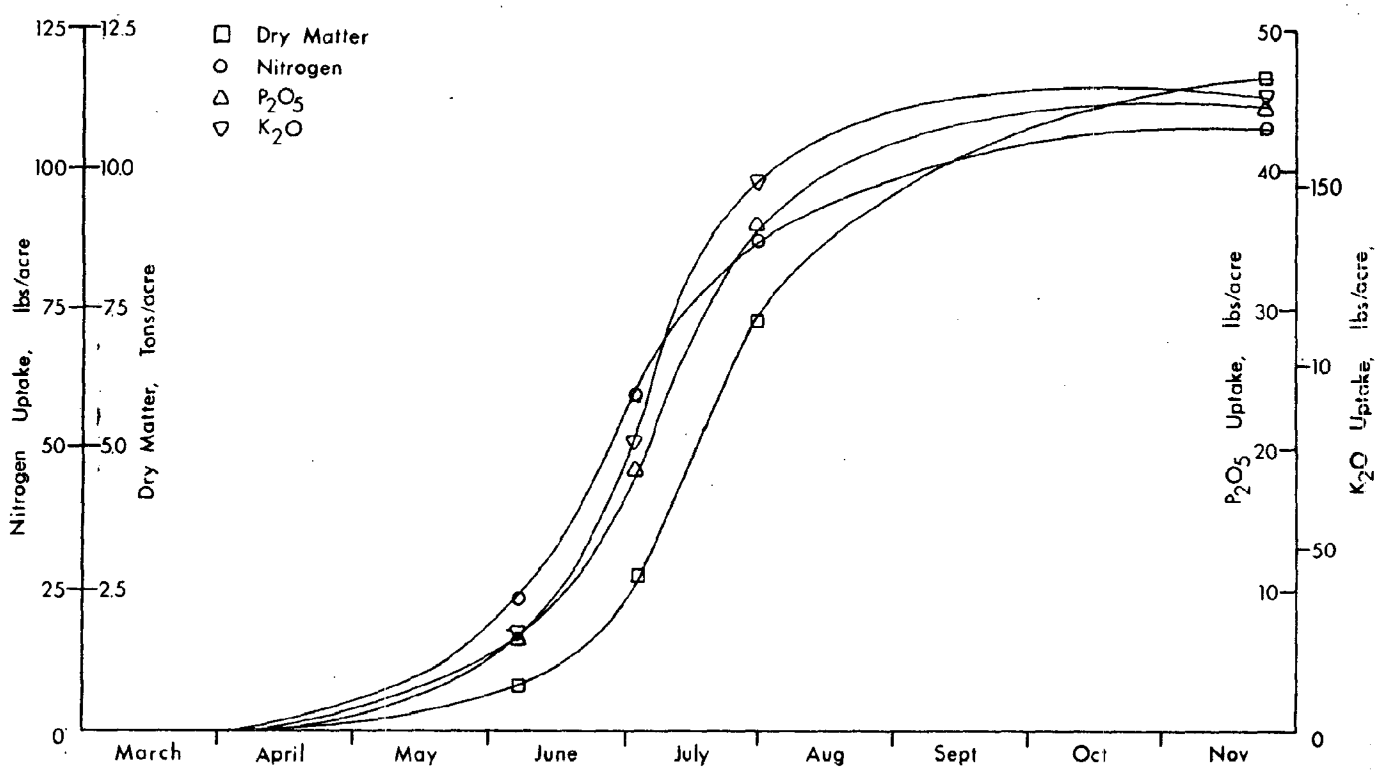

Fig. 19. Uptake rates over time for nitrogen and P_2O_5 in sugarcane.

Part II • Land Loss

by N. J. Craig, R. E. Turner
and J. W. Day Jr.

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Part II

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ABSTRACT

The causes and consequences of wetland losses in coastal Louisiana are examined in this paper. The coastal zone area, particularly the Barataria Basin, has been inventoried by several different mapping techniques. Some of these methods appear to underestimate actual land loss, perhaps by as much as 50 percent. It appears the use of photomosaics most accurately delineates land loss and the true density of canals. Total wetland loss in the Barataria Basin, calculated from Gagliano and van Beek (1970) for the interval 1890-1960, is 1,908 acres per year. The data of Adams et al. (for the interval 1960-1974) indicates total marsh area losses between 3,135 to 6,510 acres per year for the basin. The rate of land loss in the Barataria Basin appears to be accelerating. Of all land loss occurring in the coastal zone, 75 percent is in the brackish and saline marshes.

Land loss is a cumulative impact, the synergistic result of many impacts both natural and man-induced. Natural land losses are due to land subsidence, natural decay of abandoned river deltas, and erosion due to wave energy and storms. Man-induced land losses result from flood control practices, impoundments, and dredging of canals and channels with their subsequent widening. Wetland loss also results from the placement of spoil upon the marsh and impounded areas which are drained for land reclamation.

In the Barataria Basin 2.6 percent of wetland area has been converted to canals. The total wetland area lost due to canals may be close to 10 percent if spoil area is included. The interrelationship between hydrology, land, vegetative type, substrate, subsidence, and sediment

supply are complicated, however hydrologic units with high canal density are generally associated with higher rates of land loss. Natural land losses are magnified by man-induced losses and the activities of man are becoming the principle determinant of the rate and nature of land loss.

Some of the cumulative impacts of land loss are: increased saltwater intrusions, a loss of a capacity to buffer the impact of large additions of nutrients, and a reduction in storm buffering capacities. One measure of the impact is that approximately 8-17 x 10^6 dollars of fisheries products and services are annually lost as a consequence of present land loss.

Land loss, when viewed at a basin level, transcends the differences in local vegetation, substrate, geology, and hydrology. Management concerning land loss should, therefore, focus at the basin level. Management concepts and guideline recommendations revolve around the need to appreciate the long-term interrelations of the wetland estuarine system.

I. Introduction

Land loss in Louisiana's coastal zone is a problem which has broad environmental and economic ramifications. The cumulative impacts resulting from land loss include (1) changes in hydrology which contribute to an increase in saltwater intrusion and eutrophication; (2) losses in storm buffer capacity; (3) a decrease in waste assimilation by wetlands; and (4) diminishing nursery grounds for Louisiana's coastal finfish and shellfish resources. Land loss is the consequence of many interacting factors, including flood control, navigation improvement, impoundments, canalization, and channelization as well as natural biological and geological processes. Land loss, when viewed at a basin level, transcends differences in local vegetation, substrate, geology, and hydrology.

The coastal area of southern Louisiana is the result of sediment deposition by the Mississippi River over the past 5,000-10,000 years since the last rise in sea level. The broad nature of the deltaic plain results from the frequent channel changes by the Mississippi River, creating extensive areas of near-sea level marshes and swamps (Frazier 1967).

In an active delta complex, deposition of sediments will exceed erosion and there is a net land gain. In an abandoned delta, the reverse holds true. Historically in Louisiana, the loss of land in an old delta was compensated for by the building of new land in the active delta. This is no longer the case. Due to the extensive man-made levee system along the Mississippi, overbank flooding has been virtually eliminated and much of the sediment is deposited along the continental shelf in deep Gulf of Mexico waters. Although the Atchafalaya is creating new sub-deltas, it is not keeping up with the rate of land lost throughout the coastal zone.

The coastal land that is lost is generally wetlands (marsh and swamp). This occurs in three basic ways: (1) Wetland can be converted to open water due to natural or man-made processes. Land loss of this type can be caused by erosion, or by dredging to form canals, channels, harbors, etc. (2) Wetland can be covered with fill material and converted to terrestial habitat. This type most often results from the placement of spoil from dredging. Examples of this type are spoil levees formed along channels and canals and also along "fingerfill" type impoundments. (3) Wetlands can be partially or completely isolated by levees. Some impoundment areas are permanently flooded to enhance waterfowl populations and/or maintain freshwater conditions. Examples of this type of impoundment are on the Sabine and Lacassine National

Wildlife Refuges. Other diked areas are often drained, most frequently by pumping, for agricultural or urban purposes. Most of metropolitan New Orleans is drained wetlands.

We will define land loss as the substantial removal of land from the ecological role it played under natural conditions. This definition includes all three types of wetland alteration mentioned above.

Objectives

We have four objectives in this paper:

(1) To review the existing information and make a qualitative and quantitative documentation of land loss in coastal Louisiana.

(2) To determine the relative importance of various processes in causing land loss.

(3) To investigate the cumulative impacts of land loss.

(4) To present management guidelines, recommendations, and data needs.

II. Documentation of Land Loss

Several inventories have been made of water bodies (including canals and impoundments) in Louisiana's coastal zone. These surveys were undertaken by Adams et al. (1976), Barrett (1970), Chabreck (1972), and Gagliano and van Beek (1970). The results of these studies are not completely consistent, therefore, we feel that an analysis of the methods and results is necessary.

A. Adams et al. (1976) Inventory

Adams et al. measured the man-made features within the Barataria Basin Management Unit from the 1969 New Orleans District Corps of Engineer's uncontrolled photomosaics. Different areas were computed automatically using a

Calmagraphic II Digitizing System. Where coverage by the photomosaics was not complete, the latest editions and largest scale USGS quadrangle charts were used. The resolution included all canals and impoundments that show areal extent on a standard 7 1/2 minute quadrangle chart.

The use of uncontrolled photomosaics results in some loss in accuracy, but the interpretation is not difficult and boundaries can be easily determined. The use of one scale (1:20,000) and one date for the inventory of the entire area yielded reproducible data (Adams et al. 1976). Twelve types of man-made features were recorded: rig access canals, pipeline canals, oil field navigation canals, navigation canals, transportation embankments, agricultural drainage canals, agricultural impoundments, industrial impoundments, urban drainage canals, agricultural commodity-transportation canals, oil field embankments, and mineral extraction navigation canals. These were all computed by environmental unit (saline, brackish, fresh marsh and swamp). Of these man-made features, rig-access canals are the most important components of land loss in saline and brackish marshes while agricultural impoundments are most important in fresh marshes and swamps. Areas of these man-made features are presented in Table 1.

Canals in the Barataria Basin are 1.5 percent of the total area (including marsh, swamp, and topographic high land and water) and 2.6 percent of the total wetland area (saline, brackish, fresh marsh and swamp forest).

Barataria Basin - Percentage of Wetland Area

	Saline	Brackish	Fresh	Swamp	Total
Canals only	3.8%	3.7%	2.1%	.94%	2.6%
All man-made features	3.8%	4.6%	8.4%	7.7 %	4.9%

TABLE 1. AREAS OF MAN-MADE FEATURES IN THE BARATARIA BASIN MANAGEMENT UNIT (From Adams et al. 1976).

	Environmental Units (sq. miles)				
Man-made features	Saline	Brackish	Fresh	Swamp	Total
Rig Access Canals	5.29	11.68	5.21	1.09	23.27
Pipeline Canals - 65 ft width	2.23	1.65	.48	.20	4.56
Pipeline Canals - 130 ft width	.29	.05	.16	0	.50
Oil Field Navigation Canals	.02	.19	.19	0	.40
Navigation Canals	.87	1.98	.5	1.18	4.53
Transportation Embankments	0	.43	.51	.48	1.42
Agricultural Drainage Canals	0	.91	.82	.98	2.71
Agricultural Impoundments	0	3.55	21.39	6.06	31.00
Industrial Impoundments	.05	0	0	.07	.12
Urban Drainage Canals	0	.40	.10	.07	.57
Agricultural Commodity - Transportation Canals	0	.03	0	.02	.05
Oil Field Embankment	0	0	0	.22	.22
Mineral Extraction Navigation Canals	.61	0	0	0	.61
Other	.05	0	0	0	.05
	9.41	20.87	29.36	10.37	70.01

Summary:

Environmental Unit	Total area of all man-made features	Total area of canals (sq. miles)
Saline	9.41	9.36
Brackish	20.87	16.89
Fresh	29.36	7.46
Swamp	10.37	3.54
Total	70.01	37.25

Land loss rates were determined for different environmental units -- salt, brackish (including intermediate) and fresh marsh -- within Lafourche, Jefferson, and Plaquemines parishes in the Barataria Basin. Fourteen sampled areas were selected to measure land loss throughout the years 1960, 1971, and 1974. USGS quadrangle sheets (7 1/2 and 15 minute scale) were used for the 1960 base information. For 1971, USGS orthophoto quadrangles were utilized and where possible, NASA infrared color photographs were used. Infrared color photographs (NASA Mission 293) were used to obtain 1974 data (Adams et al. 1976).

The figures showed considerable variation for test sites within the same environmental unit. A high and low annual value were presented as below:

Salt Marsh -- loss 1,262 to 959.3 acres/year
Brackish Marsh -- loss 3,872 to 1,299 acres/year
Fresh Marsh -- loss 1,376 to 876.8 acres/year
Total combined marshes -- loss 6,510.4 to 3,135.3 acres/year

B. Barrett's Inventory

Barrett (1970) measured the area of canals, natural channels, and water bodies south of the Intracoastal Waterway and surrounding Lakes Pontchartrain and Maurepas. The total area studied comprised 11,055 square miles. The surface area of large water bodies was measured by planimeter; the area of canals and streams was determined by multiplying the measured length by the average width. Maps scales used ranged from 1:250,000 to 1:24,000. The dates of individual maps also varied considerably ranging from 1948 to 1969. Although mapping in coastal Louisiana has been generally very complete, in some instances the most recent maps were 21 years old (Gagliano 1973). It is probably that because of the age of some maps used, a large percentage of the more recently developed canals were not included in this inventory. Therefore, the estimates should be conservative.

Barrett reported that there were 4,572 miles of canals and 7,227 miles of natural channels (Bayou and Passes) in the coastal zone. The total area of canals and channels was 42,004 acres (65.8 sq. miles), or 0.6 percent of the total study area.

C. Chabreck's Inventory

Another study which generated information on the areas of canals was done by Chabreck (1971). The measurements were a product of a helicopter survey of marsh vegetation and soils. Sampling was at 0.25 mile intervals along north-south traverse lines spaced at 7.5 minutes of longitude along the coast. The total study included 12,224 square miles. Surface features were recorded at 7,127 different points, from which surface areas of various water body classes were determined.

Canals were recorded as a point and the total points representing canals were taken as a percentage of the total acreage. Chabreck estimated that the total acreage of canals was 5,198 or 1.1 percent of the area sampled in Barataria Basin, and 47,475 acres or 0.7 percent of the entire coastal zone.

D. Gagliano's Inventory

Gagliano and van Beek (1970) determined net land loss in the Louisiana coastal zone from 1890 through 1960 (See Fig. 1), U.S. Geological Survey maps at scales of 1:24,000 and 1:62,500 were used, and 80,580 sample grid points were evaluated in a study area of 20,400 sq. miles. These data were used to establish rates of change of land/water ratio. Results of the study indicated that land is being lost in the Louisiana coastal zone at a rate of 16.5 miles^2 per year.

Gagliano's estimate of canal acreage of 0.9 percent of the coastal zone seems conservative compared to Adams et al. It appears that linear features such as navigation and pipeline canals may be underestimated by the point-counting method.

A comparison of the size of the study area, percentage canal area/ marsh area, and methodology of each inventory is provided in summary form in Table 2.

E. Land Loss by Vegetative Type and Management Unit

To obtain a general idea of land loss by environmental units and management units, a composite map was created by superimposing Gagliano (1970) map of land loss and gain in the coastal zone over Chabreck et al.'s (1968) map of vegetative types (environmental units) (see Fig. 1a&c). This composite map was digitized to determine land loss in acres per year per vegetative type for the seven management units of the Louisiana coastal zone (see Table 3).

These results indicate that the brackish marsh is deteriorating at a higher net rate than any other wetland type (Table 3). The total rate of land loss for brackish marsh across the state is 3,320.2 acres per year, 1,704.2 acres per year for saline marsh, 1,212.5 acres per year for fresh marsh, and 541.7 acres per year for the swamp forest.

F. Summary

The Barataria Basin has been inventoried by several mapping methods. It appears that photomosaics most accurately delineate the true density of canals and total marsh area in the Barataria Basin. The accuracy lies in the fact that it gives complete coverage of the coastal zone during a single year period, in contrast to maps whose dates may vary as much as 20 years. The scale for the photomosaics is 1:20,000. The photomosaics are all recent and are a direct picture of the area. Their use is much preferred over the use of maps,

TABLE 2. SUMMARY OF INVENTORY RESULTS

Area	% Canal/ Marsh	Methodology	Reference
Barataria Basin (2,427 sq miles)	2.6%	photomosaic	Adams et al. (1976)
Barataria Basin (2,015 sq miles)	1.1%	points counted by helicopter from preselected transects	Chabreck (1972)
Barataria Basin (to Intracoastal Waterway, 1,370.5 sq miles)	1.0%	map measurement with various dates and scales	Barrett (1970)
	% Canal/Total Area Marsh and Water		
Louisiana Coastal Zone (20,480 sq miles)	.9%	point count samples of 2 series of maps, 80,560 pts per series	Gagliano et al. (1970)
Louisiana Coastal Zone (12,224 sq miles)	.7%	points counted from preselected transects	Chabreck (1972)
Louisiana Coastal Zone (11,055 sq miles)	.6%	map inventory	Barrett (1970)

TABLE 3. LAND LOSS (ACRES/YEAR) PER VEGETATIVE TYPE AND % OF TOTAL LAND LOSS FOR MANAGEMENT UNITS OF LOUISIANA COASTAL ZONE CALCULATED FROM FIG. 1 (1890-1960).

Management Unit	Saline Marsh	Brackish Marsh	Fresh Marsh	Swamp Forest
Pontchartrain - St. Bernard	399 24%	1060.6 64%	7.4 1%	178.3 11%
Mississippi River	3.7 1%	232.8 37%	286.2 62%	
Barataria Basin	818 40%	901.9 44%	188.2 9%	142.7 7%
Terrebonne Basin	441 30%	454.1 31%	411 28%	167.2 11%
Atchafalaya River*	1.7 1%	11.6 9%	105.6q 78%	16.2 12%
Vermilion Basin	12.9 3%	397.8 84%	27.3 6%	37.3 7%
Chenier Plain	27.9 6%	261.4 55%	186.9 39%	
TOTAL	1704.2 25%	3320.2 49%	1212.5 18%	541.7 8%

*This does not include the current delta building in the Atchafalaya Bay.

especially older maps, of the 1930s, when surveying techniques were not accurate, and in which canals and other features appear to be stylized.

Within the entire coastal zone, canals alone are equal to at least 0.9 percent of the total present area of marsh and water. If we assume a marsh:water ratio of 1:1.52 (Chabreck 1971), this equivalent to at least 1.37 percent of the present marsh area. This latter estimate is low because of the techniques used and does not include significant amounts of other man-made features. The greatest rate of land loss is occurring in the brackish and saline marshes (74 percent of all land losses). The land loss data calculated from Gagliano and van Beek (1970) are for intervals 1890-1960. The data of Adams et al. is for the interval 1960-1974. A comparison of the two data sets for the Barataria Basin is presented below:

	CALCULATED FROM	
	Gagliano and Van Beek	Adams et al.
Salt Marsh	loss 818 acres/yr	loss 1,262.4 to 959.3 acres/yr
Brackish Marsh	loss 902 acres/yr	loss 3,872.0--1,299.2
Fresh Marsh	loss 188 acres/yr	loss 1,376 to 876.6
Total Marsh Area	loss 1,908 acres/yr	loss 6,510.4--3,135.3

The rate of land loss determined by Adams et al. is significantly higher than that calculated from Gagliano and van Beek. This may be because of the methods involved. Tests comparing digitized areas and point-counted results yielded similar findings (Adams et al.). The only difference between the two methods, then, could be due to the sources of information. Gagliano employed maps dating back to 1890. Adams et al. used 1960 quadrangle maps and 1971, 1974 aerial photography. It is not likely that these methods can account for the large differences in land loss rate. Therefore it seems that the rate of land loss in the Barataria Basin is accelerating.

III. Causes of Land Loss

Land loss is a cumulative impact, the synergistic result of many individual and multiple impacts. These impacts are both natural and man-induced. Natural land loss is caused by subsidence and net erosion in abandoned river deltas, while land loss caused by man results from such activities as reclamation and dredging. In this section of the paper we will discuss the various causes of land loss and their relative importance.

A. Natural Land Loss

1. Land Subsidence

Land subsidence, the lowering of land surface relative to sea level, plays an active role in the coastal zone. The causes of subsidence are (1) eustatic sea level changes, (2) regional subsidence caused by base downwarping (isostatic adjustment) from sedimentary loading (3) compaction of sediments (discussed below) and 4) tectonic activities including faulting, folding, fracturing, and flowing within the thick sedimentary section (Adams et al. 1976).

Compaction of sediment is a result of several factors, some of which are caused by man.

a) Differential consolidation owing to textural variability in the sediments. (natural)

b) Consolidation of underlying sediments from weight of features such as natural levees, beaches, artificial levees -- particularly when the features have been deposited over weak compressible foundations. (both natural and man-made) losses of the sediment are high as are resulting subsidence rates. As connate fluids are lost, the rate of compaction and subsidence gradually diminishes (Morgan and Larimore 1957).

3. Loss of Barrier Islands and Inlet Widening

Barrier islands, such as Timbalier Island, Grand Isle, and Grand Terre are a strong defense against marine processes and hurricanes. The tidal passes associated with barrier islands can be viewed in part as control valves of the estuaries (Gagliano 1973) because they regulate the amount of salinity intrusion, storm energy, etc. that enters the estuaries.

The barrier islands along the coast are undergoing erosion. In the Barataria Basin, the barrier islands Grand Isle and Grand Terre were listed as areas of "critical erosion" by U.S. Army Corps of Engineers, National Shoreline Study. Between 1960-1972, 172 acres (18 percent) of the principal Grand Terre island was eroded away. Between 1932 and 1969 the average rate of barrier island erosion in the Barataria Basin was 119 acres per year. The width of the tidal passes in the Barataria Bay area is increasing as is the rate of increase of width (Table 5).

The coastal erosion of the barrier islands is due to lack of sedimentation from the Mississippi River regional subsidence, hurricane damage and man-induced changes such as dredging of canals on the bayside of a number of islands (Gagliano 1973).

4. Type of Substrate

Land loss will be locally affected by the substrate type, i.e., clay, silt, peaty areas, natural levees, beaches, etc. Across the coastal zone, particularly in the deltaic plain, the substrate is highly diverse and in many cases unstable, resulting in a complex, variable

c) Local subsidence of compressible materials through consolidation or displacement by objects such as buildings, pile structures, fills, bench marks, and tide gages. (man-induced)

d) Lowering of water table through extraction of groundwater, salt, or sulfur; also "reclamation" practices that employ diking, construction of water control structures, and drainage of lands for agriculture or flood protection. (man-induced)

e) Extraction of oil, gas, sulfur, and water from salt domes is known to have resulted in subsidence. (man-induced)

The direct supply of sediment from the Mississippi River which could balance the affect of subsidence has been eliminated due to levee construction. Some compensatory sedimentation comes from the organic matter deposited on the floor of the marsh and estuary by marsh plants, but it is not enough to counteract the subsidence rate.

2. <u>Delta Growth and Decay</u>

Coastal Louisiana is the result of deposition of the Mississippi River sediments in different delta lobes during the past 5,000-10,000 years since the last rise in sea level. The modern Birdfoot delta is the latest of seven major lobes of the Mississippi (see Fig. 2). For the past several thousand years, the Mississippi River has followed a pattern of extending a delta seaward into the Gulf in one area, and after a few hundred years, abandoning it gradually in favor of a shorter adjacent route of steeper gradient (Morgan and Larimore 1957). The abandoned deltas are in various stages of decay. Table 4 lists the approximate ages of several deltaic units.

Rates of subsidence and erosion of an abandoned subdelta follow a decelerating pattern. Immediately upon abandonment, interstitial water surface (Adams et al. 1976). A three-dimensional knowledge of an area can help explain local variations in land-loss rates. For example, a network of natural levees, at the surface or submerged, provide a more solid, stable substrate than the surrounding marsh. These areas are capable of withstanding erosional forces such as wave attack for longer periods of time. St. Mary's Point, a remnant of a natural levee in Barataria Bay, is such an example. In Lake Salvador, Little Lake areas, there are several examples of old channels which are eroding more slowly than surrounding marshes. Organic soils, such as muck (20 percent-50 percent organic content) and peat (50 percent or greater organic content) are more unstable and more susceptible to the natural and man-made forces influencing land loss.

B. Man-induced Alterations

1. Flood Control

The Mississippi River deltas historically have been areas of dynamic change as a result of fluvial processes advancing the delta seaward and marine erosion coupled with subsidence encouraging delta retreat. As a result of many years of levee construction, the Mississippi River has been effectively "walled in." The levee line on the west bank begins just south of Cape Girardeau, Mo., and with its incorporated structures (except where the St. Francis and Arkansas-White Rivers join the Mississippi) extends unbroken to the Gulf of Mexico. The east bank is protected by levees alternating with high bluffs. When major floods occur and the carrying capacity of the channel is exceeded, relief outlets through Birds Point-New Madrid, Atchafalaya Basin, and Bonnet Carre floodways are opened and the flat lowlands at the junctions of tributaries with the Mississippi are flooded (Mississippi River Commission 1964).

These flood control measures have interrupted the balance between riverine and marine processes causing sediment transport, deposition, and valuable fresh water nutrients which built and stabilized the marsh and swamp areas to be virtually eliminated in coastal Louisiana. Most of the sediment and nutrients of the river are now being deposited in the deep Gulf of Mexico and do not contribute to the construction or maintenance of the coastal wetlands. The development of the Atchafalaya Delta is an exception.

2. Canals

Canals built for oil recovery, navigation, and other activities densely interlace the coastal zone. The construction of these canals has led to direct land loss by dredging and spoil deposition and to changes in hydrology. In section II the areal extent of canals was documented. In this section, canal widening and spoil banks will be discussed.

a. Canal widening

"Many channels began as small significant pirogue ditches, which allowed the trapper to successfully work in the alluvial wetlands. However, through repeated use, storms, and current flow, they enlarged so sailboats and an occasional lugger could take advantage of the channel and have become major landscape features. They are now permanent. The only indications of human origin lie in their straightness and relationship to the natural waterway. The work of the canal builders continues to have a decisive and cumulative impact on wetlands environment. Some trails (trainasse) are over 100 years old and have become a vital part of the total transportation network; they are a visible segment on the landscape and have affected drainage patterns, influenced salinities, and are a reminder of man's abilities to unknowingly change the delicate balance in the natural system" (Davis 1973).

There are numerous example that demonstrate the widening of various canals over extended periods of time. Canals widen through usage, generally as a result of wave action, and altered hydrological pattern. Another important factor is the condition of the marsh substrate; the softer or more fluid and organic the marsh, the more susceptible it will be to erosion (Table 3).

i. Example of pirogue canal widening

One extreme example of canal widening is in the Barataria Basin. Fifty years ago Matthew Creppel used a pirogue paddle to cut a 40-inch wide, 12-inch deep ditch (trainasse) between two bayous in the vicinity of Bayou St. Denis in Barataria Bay. Today this trainasse has eroded into a bayou 200-feet-wide and 8 to 10 feet deep. There is no evidence this canal has ever been dredged. The widening has probably resulted in a change in circulation patterns. Other settlers recall when large parts of the basin were trapped using trainasses. Many of these trapping regions are gone, eroded away, the ditches having enlarged into major channels or coalesced to form larger water bodies (Davis 1973).

ii. Rockefeller Wild Life Refuge

Lewis Nichols conducted several studies concerning the erosion of some of the numerous canal banks on the Rockefeller Wild Life Refuge (Nichols 1958, 1959). He presents examples of canals, relating to oil field activities on the Chenier Plain of Louisiana, and their widening over extended periods of time (See Fig. 3).

Humble Canal, extending from East End Headquarters on the Grand Chenier Ridge Complex to Joseph Harbor Bayou (5.26 miles), was originally dredged as 65 feet in width in 1940. In 1953, it was redredged to a width of 65 feet. Since 1954 the canal has widened at a rate of 1.16 feet per month (as of 1958). The canal is used by:

1. Union Producing field development (6 wells) and production.
2. Shell Oil Company offshore field development standby usage, since the fall of 1954.
3. Rockefeller Refuge management usage.
4. Royalite Lease exploration (3 wells, nonproductive).

Each of these four sections of the Humble Canal widened at different rates over the five-year period:

1. East End Headquarters to Union Producing Junction,

    Average width . . . . . .135 feet
    Increase. . . . . 70 feet
    Usage . . . . 1,2,3, and 4 (refer to units itemized above)

2. Union Producing Junction to Joseph Harbor Bayou,

    Average width . . . . . .121 feet
    Increase. . . . . 56 feet
    Usage . . . . 2,3, and 4.

3. Union Producing Junction to Field,

    Average width . . . . . .110 feet
    Increase. . . . . 45 feet
    Usage . . . . 1 and 3.

4. Joseph Harbor Bayou to Royalite Lease exploration,

    Average width. . . . . .105 feet (approximate - one section)
    Increase . . . . 40 feet
    Usage. . . . . 3 and 4.

On Humble Canal the average canal and levee width is 239 feet, equivalent to a land loss of 24 acres per mile of canal. Union Producing Canal averages 37 acres of land lost per mile of canal, and the Royalite lease canal approximately 37 acres per mile. By 1958, the entire Humble system contained 504 acres of wetland lost as a result of canal construction (Nichols 1958).

Another example is the Superior canal system. Construction began in the winter of 1951-52, and when finished had a total of 15.3 miles of canals and well locations. The canal system is a freshwater system and all canals and well locations are lined with levees. All canals were constructed 65 feet in width and the spoil placed to make continuous levees on both sides. The Superior Canal system is used for field development and production. The total area of wetland lost to refuge management from canal and well construction was 648 acres as of 1958 (Nichols 1958).

Width of the Superior Canal (1952-1958).

Constance Bayou Field

1. Main Canal - Center of Section 4, T15S, R3W

   Initial width . . . . . . 65 feet
   Present width . . . . . .158 feet
   Increase. . . . . 93 feet

   Present Canal is 243% wider than initially.

2. Main Canal - NW Corner of NE 1/4 of Sec. 15, T15

   Initial width . . . . . . 65 feet
   Present width . . . . . .137 feet
   Increase. . . . . 72 feet

   Present Canal is 210% wider than initially.

Deep Lake Field

3. Main Canal - Center of SW 1/4 of Sec. 14, T15S, R

    Initial width . . . . . . 65 feet
    Present width . . . . . .150 feet
    Increase. . . . . 85 feet

Present Canal is 231% wider than initially.

4. Main Canal - Center of NE 1/4 of Sec. 23, T15S, R3W

    Initial width . . . . . . 65 feet
    Present width . . . . . .137 feet
    Increase. . . . . 72 feet

Present Canal is 210% wider than initially.

iii. Golden Meadow oil field

A study done by James H. Blackmon (personal communication) on the Golden Meadow oil field represents canal widening over time. Blackmon looked at Department of Agriculture 1:20,000 black and white photographs of the Golden Meadow oil field taken in 1940 and 1953. For the year 1969, he used U.S. Corps of Engineers 1:20,000 black and white uncontrolled mosaics (See Figures 4, 5, and 6). Tracings of these maps were digitized by Craig to determine canal widening over time. A summary of the increase of canal area over time is given in Table 6.

iv. Summary of canal widening

From these examples it is evident that canal widening is occurring throughout the entire coastal zone, influencing the geologically more stable Chenier Plain as well as the Deltaic Plain. Its influence also transcends the various marsh types; affecting fresh, brackish, and saline marsh. The annual increase in canal width ranges from about 2 to 14

TABLE 4. DELTAIC UNITS OF MISSISSIPPI RIVER AND CARBON-14 AGE (MORGAN AND LARIMORE 1957)

Deltaic unit	Carbon-14 age of Deltaic Units: years ago before present
Late Lafourche Subdelta	About 200 to 300
Early Lafourche Subdelta	800 to 1500
Barataria Area (Barataria-St. Bernard Subdelta)	2200 to 2700
St. Bernard Area (Barataria-St. Bernard Subdelta)	2200 to 2700
Teche Subdelta	3000 to 3500
Maringouin Subdelta	4800

TABLE 5. CHANGE IN WIDTH OF MAJOR PASSES IN BARATARIA AREA (FT.) (VAN SICKLE ET AL. 1976).

Pass	1932	1954	% Year Change	1969	% Year Change
Barataria	2,149	2,373	.45	3,500	2.59
Abel	212	499	3.89	1,233	6.03
Quatre Bayou	2,181	2,921	1.32	3,700	1.57

TABLE 6. CANAL AREA OVER TIME (ACRES)

	Canal				
Year	AE	BF	GC	BH	Total
1940	28.1	5.1	8.3	16.6	58.2
1953	36.4	8.3	14.0	21.7	80.6
1969	58.8	10.8	24.3	25.6	119.6

TABLE 7. ANNUAL INCREASE OF CANAL WIDTH (K) AND THE TIME NECESSARY TO DOUBLE THE CANAL AREA (dt). THE DATA ARE EXTRAPOLATED FROM THE PREVIOUS SIX TABLES.

Example (years of survey)	Annual Increase Of Canal Width K (% per year)	Doubling Time (years)
A. Bayou St. Denis 1926-1976	8.2	8.4
B. Humble Canal 1953-1958	1) 8.3	8.3
	2) 7.5	9.3
	3) 6.9	10.1
	4) 6.5	10.7
C. Superior Canal 1952-1958	1) 14.8	4.7
	2) 12.4	5.6
	3) 13.9	5.0
	4) 12.4	5.6
D. Golden Meadow	1) 2.0	34.8
1940-1953	2) 3.7	18.5
1953-1969	3) 4.0	17.2
1940-1953	4) 2.0	33.6
1953-1969	5) 3.0	33.1
	6) 4.6	42.1
	7) 3.0	20.1
	8) 2.0	67.1

percent per year for a doubling time of 5-60 years (Table 7). There is an apparent relationship between the size of the canal and the increase in width (Figure 7). The larger the canal the faster it widens. This may reflect the amount of boat traffic but certainly could reflect the impact on the hydrologic flows since the larger the canal the larger the water mass is that can move through it. To put this in perspective, as previously stated, Gagliano estimated that 16.5 mi^2/yr or <.3 percent of coastal Louisiana's land is being lost each year due to all factors -- natural and man-made. Canals, which represent 2-4 percent of the land, are widening at a rate an order of magnitude greater and may eventually be the dominant factor in causing land loss in Louisiana - simply by widening at this current rate. For example, assume an enlargement rate of 5 percent/year. This is equivalent to a doubling rate of 14 years. Thus in 14 years the present 2.6 percent canal density in Barataria Bay (Table 1) may become 5.2 percent of the total area or ~10.0 percent by the year 2001.

These figures are preliminary estimates but the analysis indicates that further work is warranted on this subject. It seems likely that either boat traffic or increased water flow in the canals may contribute to canal widening. Plugging canals, wherever possible, at both ends and at intervals between should reduce the water flow and eliminate the boat traffic, thus decreasing the annual rate of widening.

3. Spoil Banks

The discussion to this point has determined only the surface area of wetland loss due to dredging. This, however, ignores the area of spoil banks created in the process. Spoil, the material excavated by dredging, is deposited alongside the dredged area and results in the loss of wetland. Revegetation of the spoil area eventually does occur but the change in elevation causes a change in species composition. At elevations above high water, a full canopy of shrubs and small trees may develop (Monte 1975). It is also possible that marshes in the vicinity of the spoil banks deteriorate due to impact of the bank on the surrounding marsh. A specific example is the Mississippi River Gulf Outlet (MRGO). Construction of the MRGO resulted in the destruction of 23,606 acres of marsh comprising 6548 acres for the channel and 17,058 acres by spoil deposition (Rounsefell 1964). For this example the ratio of canal area to spoil area is 1:2.6.

McGinnis et al. (1972) noted that a 50-ft-wide pipeline floatation canal the direct conversion of marsh area to canal area was 6 acres per mile. The conversion of marsh to spoil levee was 12 to 18 acres per mile. For this case the canal:spoil ratio ranges from 1:2 to 1:3. They noted that the total marsh area with altered character would be in the range of 30-36 acres per mile. Nichols (1958) suggests that the area of land whose productivity is altered is 5 to 6 times that of the canal itself.

The inclusion of spoil bank area in the total figures for wetland loss indicates that canals may be much more important in land loss than previously indicated. For example, as previously mentioned, Gagliano and van Beek (1970) estimated the rate of land loss in coastal Louisiana to be 16.5 mi^2/yr. Of this, 6.53 mi^2/yr (39%) was due to canals. The following table indicates changes in the ratios of wet land loss and the percentage due to canals with different canal area:spoil area assumptions. Even the 1:2 ratio is probably an underestimate because the examples above suggest that spoil area is 2 to 3 times greater than canal area.

Canal area:spoil area	Total Wetland Loss mi^2/yr	Amount due to Canals mi^2/yr
1:0	16.5	6.5 (39%)
1:1	23.0	13.0 (56%)
1:2	29.6	19.6 (66%)

Thus during the period covered by Gagliano and van Beek's study, (1931 to 1967), wet land losses may have been much higher than he estimated. Adams et al. (1976) estimated that 2.6 percent of the wetland area in the Barataria Basin has been converted to canals. Using the same ratios as above, the total wetland area lost due to canals may be around 10 percent, if spoil area is included. The area of wetland affected by canals in the Barataria Basin may approach 20 percent of the total wetland area if the area of wetland affected by canals is 5 to 6 times the area of the canal, as previously mentioned. This suggests that the effects of canals may be much greater than formerly thought. We believe that more data are needed on both the ratio of canal area to spoil area and the indirect effects of canals.

4. Land Reclamation

Land reclamation programs have been attempted in Louisiana since the early 18th century. These drainage projects, mainly for agricultural purposes, reached a peak between 1915 and 1920. The majority of these failed due to poor drainage, deterioration of levees, seepage, and the shrinkage and oxidation of the organic soils--all resulting in land loss. The marshes of the coastal zone have numerous rectangular lakes which document the failures of these projects (Gagliano 1973).

In the early part of this century land reclamation of the wetlands for urban and industrial developments began. New Orleans is the most extreme example of this expansion. By the late 19th century New Orleans had used all the available high grounds and began expanding into the marshes and swamps. This expansion continues today. There are numerous reclamation projects in the planning today. "Active and proposed schemes related to industrial sites, nuclear power plant locations, planned communities, recreation complexes (harbor towns and fishing resorts), airports, and Florida-type waterfront communities are appearing at an alarming rate." (Gagliano 1973). Although this is not direct land loss, it is direct marsh loss and results in loss of habitat, waste buffer, storm barrier, and nursery grounds. The information in Table 1 shows that land reclamation is a major cause of land loss.

5. Other Causes of Land Loss

In much of the coastal zone, there is a trend towards increasing salinity, (Lindall et al. 1972, Pollard 1973), which is due to several factors: (1) land loss and inlet widening, (2) changes in the flow of the Mississippi River resulting in loss of freshwater input to the upper basins, and (3) specific projects such as the Mississippi River Gulf Outlet (MRGO) and the Barataria Waterway.

Canals which extend through various marsh types allow salt water, which previously had no means of reaching fresh marsh, to have swift and direct ingress into fresh areas. Small tidal channels and canals connect MRGO with adjacent marsh areas, and the dieback of oak trees along old natural levee ridge, dieback of marsh grass and enlargement of marsh ponds is probably due to the increased salinities. In some areas marginal to the channel, marsh deterioration is severe (Gagliano 1973). Changes in salinity due to the MRGO are well documented; the recording stations in the vicinity of the channel show significant changes after the channel was opened (1959) and completed (1962)

(Gagliano 1973). Similar situations exist for the Barataria Waterway, the Houma Navigation Canal, and the Calcasieu Ship Channel. There is a pressing need for more detail studies of this phenomenon.

Marsh deterioration also occurs as a result of severe storms such as hurricanes, marsh fires, and muskrat eat-outs. Occasionally during storm tides, waters with salinities above 50 percent sea water are carried into fresh and brackish marsh. If this fails to run off rapidly, the vegetation rots and results in areas denuded of vegetation (Treadwell 1955). If this occurs in fresh floating marsh, the vegetation may be completely destroyed and permanent ponds and lakes open up (Gagliano 1973). Deleterious effects of high salinity flooding caused by hurricanes are mostly felt in altered areas such as impoundments. The effects in natural marsh areas are often insignificant or transient (Chabreck and Palmisano 1973, Ensminger and Nichols 1957, Morgan 1959, O'Neil 1949, Webert 1956, Wright et al. 1970). The extent of marsh deterioration which results from muskrat eat-outs and marsh fires is not known.

C. Man-induced vs. Natural Land Loss

Land loss, as stated previously, is due to factors both natural and man-induced. Natural land loss is magnified by loss attributed to man's activities. According to Gagliano (1973) "the rate of land loss increase directly attributed to man's activities is greater than the rate of increase due to natural causes."

If land loss in the coastal zone were due solely to natural processes, it is expected that the oldest deltas would be losing land at the slowest rate, while the youngest would be losing land at the fastest. Although this is true for shoreline retreat (Morgan and Larimore 1957), it does not seem true for land loss in the four comparable areas with available data (See Table 8A and 8B).

Figure 8 shows the direct relationship between the density of canals (1969) and the land loss (1930-1969) for each hydrologic unit in Louisiana (numbered 1 through 9, east to west). For 9 specific sites in Barataria Basin (Figure 9) there is a tendency for land losses (1960-1974) to be directly related to the density of canals (Figure 10). For these sites, the average land loss is 0.21 percent per year or a 2.19 percent per decade. For a thirty-year-period this is a 6 percent decline in wetland area. Both of these examples suggest that the cumulative impact of canals is to increase natural rates of land loss.

Summarizing, canals result in direct loss of habitat through dredging and spoil disposal, and an indirect land loss effect due to changes in hydrology, eutrophication, saltwater intrusion, and acceleration of marsh deterioration. The increase of man-made water bodies has had a secondary effect of increasing the rate of loss attributed to natural causes.

D. Summary of Land Loss

The coastal zone is the result of a balance between marine and riverine influences. Landing building is due to sediment deposition from delta progradation and overbank flooding, and to a minimal extent compensatory sedimentation from organic matter deposited by marsh plants. The rate of this land building is modified by water flow, type of sediment, water depth, and vegetation.

Flood control measures and navigation projects have interrupted the natural balance between riverine and marine processes which built and stabilized the marsh areas.

TABLE 8A

	Deltaic Units	Shoreline Retreat (feet/year-average)	Age of Unit (years ago)
1)	Late Lafourche	62.0	200 to 300
2)	Early Lafourche	27.0	800 to 1500
3)	Barataria Area	16.0	2200 to 2700
4)	St. Bernard Area	13.7	2200 to 2700
5)	Teche Subdelta	9.2	3000 to 3500
6)	Maringouin Subdelta	7.5	4800

TABLE 8B

	Deltaic Units	Land loss rate (acres/yr)	Age of Unit
1)	Barataria Area	2050.8	2200 to 2700
2)	St. Bernard Area	1645.3	2200 to 2700
3&4)	Late and Early Lafourche	1473.3	200 to 1500

A. Morgan and Larimore
B. Land loss map-Table 3

The other synergistic factors influencing land loss are the following:

1. Subsidence
2. Loss of barrier islands and inlet widening
3. Type of substrate
4. Loss of sediment input
5. Shoreline retreat
6. Salinity changes
7. Canals and spoil areas
8. Land reclamation projects, impoundments
9. Hurricanes, marsh fires, animal eat-outs
10. Erosive forces-currents, wave energy, etc.

These factors, both natural and man-made, interact in a complex manner. For example, the loss of sediment input increases the rate of loss of barrier islands and inlet widening. This in turn increases the rate of salinity intrusions and erosion.

There is an apparent direct relationship between the size of the canal and its rate of widening. An altered hydrological pattern seems to be the principal cause for this relationship. The implication is that canal construction has long-term impact beyond the actual loss of land used for canal itself. In addition, the area of spoil and levees created in the building process and maintenance is at least 1:2 for canal to spoil, and often higher. An estimated 10 percent of the wetlands in Barataria Basin (the only basin with a strong data base) have been lost due to canal construction activities.

IV. Cumulative Impacts of Land Loss

The cumulative impacts of land loss are deleterious to the environmental and economic quality of the coastal zone. The impacts are changes in the hydrology of the various systems resulting in saltwater intrusion and eutrophication, loss of an important storm buffer, loss of the waste treatment afforded by healthy marsh, direct loss of habitat, and loss of nursery grounds of commercially important fish and shellfish.

A. Salinity Changes and Eutrophication

As previously mentioned, there are trends of increasing salinity in much of the coastal zone. Increasing salinity is a cause of land loss, and land loss in turn may result in increasing salinity. As the saline marsh deteriorates, the hydrology of the system changes and salt water may extend into the brackish marsh causing more land loss, creating a positive feedback loop with no control. In the Barataria Basin this is coupled with a reduction of fresh water input from the upper basins (flushing of fresh water) which could reduce the effect of saltwater intrusion.

Canals short circuit the natural flow of nutrient-laden water into lakes and bays rather than allowing it to trickle through the wetlands. This flow of water from urban run-off, agriculture, and sewage goes directly into water bodies via canals causing hypereutrophic conditions in the lakes and bays. A study done by Craig and Day in Barataria Basin indicates that if present rates of development which lead to increased eutrophication, and salinity intrusions continue, there is the potential for the degradation of the nursery grounds of the commercial fisheries associated with Barataria Basin.

B. Waste Buffer

The eutrophic conditions created by shunting nutrient-laden water into lakes and bays can be mitigated by allowing the water to trickle through the basin where the nutrients are taken up by wetland vegetation. Marshes have evolved adaptations to high nutrient levels and can remove and recycle inorganic nutrients (tertiary treatment) at a much cheaper cost than if done artificially by man. In Barataria Basin, this "free work" of nature would be equivalent to 5.6-23.6 million dollars per year if using overland flow waste treatment were used rather than tertiary treatment. This would also serve to increase marsh productivity (Craig and Day 1976). Loss of marsh is loss of this important waste buffer. An acre of marsh-estuary (calculated from mid-Atlantic estuaries which are overtaxed) is capable of doing about $14,000 worth of tertiary treatment (inorganic nutrient removal) per year at a daily loading of nutrients equivalent to 19.4 lb BOD, assuming the cost of artificial treatment is $2 per lb BOD. In other words, this is what it would cost to artificially treat this waste, if the land were not available to do this work (Gosselink et al. 1974).

C. Storm Buffer

The salt marsh acts as important storm buffer, absorbing the energy from the waves created by the storm and providing a water reservoir for storm waters. "Some idea of the protective value of a wide band of energy-absorbing marshes and barrier islands is seen in the increasing national cost for 'disaster relief' in coastal areas which either lack these natural protective 'breakwaters' or where they have been filled in or bulkheaded for housing or other development." Marsh and island-protected coasts suffer comparatively little damage even in fierce hurricanes (Gosselink et al. 1974).

D. Fisheries

The impact of canal construction on commercial fisheries yields is directly related to the area of coastal wetlands affected. The result of this coupling between wetlands and fisheries yields in the coastal zone is illustrated in Figure 11, 12, and 13. Figure 11 shows the empirical relationship between shrimp yields and wetland area on a worldwide basis. The yield of shrimp per acre of wetland area is higher toward the equator but the relationship follows a consistent pattern in spite of the inaccuracies inherent in the data. The relationship between intertidal areas and fisheries yields for the Gulf of Mexico, and for inshore yields of shrimp in Louisiana as shown in Figure 12 and 13, respectively. Higher yields are associated with larger areas of wetlands and only incidently associated with larger areas of wetlands and only incidently associated with water surface area of volume. Neither of these data sets include any adjustments to compensate for movements of the fishing craft or the organisms from nursery grounds to where they are harvested or landed. Thus the official data may not record that Alabama vessels might harvest Louisiana's menhaden in Mississippi waters.

In light of these relationships and in the absence of conflicting data, we can thus directly proportion wetland losses with fisheries losses. To do this we need to estimate the yields and value of Louisiana's fisheries. The recent landings for Louisiana and the Gulf of Mexico (U.S. only) are shown in Figure 14. The recent rise in Louisiana landings is due to the opening of several menhaden processing plants in south Louisiana. The reported shrimp landings have remained essentially constant since the 1950s in spite of a much larger fishing fleet, changes in techniques, and a rise in prices. There are very large variations in annual yields (100 percent of the average for 30 years) which may mask the impact of land losses (6-10 percent for 10 years). We will use here the average yield for 1969-1973 of 1,222 x 10^6 lbs. In the future other species may be exploited, but presently the catch-per-unit effort for both shrimp and menhaden has peaked or begun to decrease. These two species represent a major portion of the landings weight and value to fisheries industry. Shrimp generally represent 60-70 percent of the total dockside or ex-vessel value (the ex-vessel value is generally 60 percent of the processed value). The price per pound of product has almost doubled in the last ten years (Figure 15), so the latest data (1973) were used to compute the ex-vessel value to Louisiana (6.7¢ per lb). This price does not include the social asthetic, recreational, or other values of marshes (see for example, Gosselink et al. 1974). The total average annual value of Louisiana fisheries based on 1973 prices and 1969-1973 landings is thus $75.4 million, ex-vessel ($109.9 million, processed). The direct loss of marshlands from spoil banks and canals is at least 2.6-5.2 percent (Table 1 and in the previous discussion) of the total area. This percentage would be higher of course if land erosion were assumed to be partially a result of canal construction, as suggested in the previous figures and discussion. Using this wetland loss, a minimum estimate is $2.9-$5.7 million annually "lost" as cumulative consequence of previous canal construction (or $4.8-$9.5 million based on the processed value). This value will change as more canals are built, previously built canals widen and/or cause further erosion, and the economic structure of the industry changes or other geological factors predominate. A proportional assessment can also be made for the impact of canals on employment. Additionally, for each dollar spent on fisheries directly, approximately $3 are spent indirectly (Jones et al. 1974). In general economic terms, this multiplier effect means that the present cumulative economic impact of land loss is a minimum of $8.7-$17.1 million annually.

V. Management Concepts and Guideline Recommendations

Land loss is an extensive problem in the coastal zone. The factors which control land loss are highly interconnected and include such things as altered hydrology, salinity changes, vegetation changes, man's activities, as well as land loss itself. At the basin level land loss transcends differences in local vegetation, substrate, geology, and hydrology. Management concerning land loss should focus at the basin level. (Knowledge of the local hydrology, geology, and ecology is necessary to understand the causes of land loss in a specific area.)

There are two means of minimizing land losses: (1) additional land can be built to offset the loss of land in other areas, and (2) reduce, where possible, the impact of those natural and man-made factors which are most important in increasing land losses.

Land building could be accomplished in several different ways. Gagliano et al. (1972) outlined a program to create man-made diversions of the Mississippi River in order to initiate new subdelta lobes, increase upper deltaic plain aggradation, and control salinity patterns. According to Gagliano, the most efficient way to build land is simply to create diversions into broad, shallow lakes and sheltered bays. To increase biological productivity, however, it may be more useful if additional subdelta lobes extended beyond the existing Gulf shoreline. At present, there are many legal problems associated with this, but if land losses in the coastal zone become critical, innovative techniques such as this will need to be employed.

Another method of land building is to develop creative means for spoil disposal in efforts to convert the spoil into viable marsh areas.

Land building, currently, is in progress in the Atchafalaya delta and could be optimized by proper management techniques.

To prevent or minimize the amount and rate of land loss due to man's activities (and to insure the continuation of Louisiana's productive wetland resources), we have formulated the following guidelines based on this study and the work of Lindall and Trent (1975). These center on avoiding the disruption of wetlands as much as possible.

1) Construct <u>no</u> new canals that connect
    a) the edge and center of a hydrological basin and
    b) fresh and saltwater areas.
2) Plug pipeline canals wherever possible at both ends and at intervals between in order to reduce water flow and eliminate boat traffic and to decrease the annual rate of widening. If a canal crosses a natural creek bank, plugs should be placed where the canal intersects the natural tributary.
3) Build no new swamp or marsh impoundments.
4) Minimize new canal construction by multiple use of existing canals, integrated planning, common use of pipeline canals, directional drilling, etc. The alignment of canals should take advantage of the existing natural or man-made channels.

5) Reserve adequate spoil disposal sites and easements on high, dry land (non-wetland areas) for future dredging; or use the spoil to build "new" marsh.

6) Avoid "fingerfill" development in wetlands by restricting residential development and canals to non-wetland areas.

7) Canal depths should not exceed that of the euphotic zone (1.8-2.0 m at mean low water) except where normal turbidity results in extremely shallow euphotic zones.

8) a) Canal depths should never exceed the depth of water body where canal terminates.

   b) Access canals should be of uniform depth or become gradually shallower proceeding inland from a central water body. This is to prevent formation of stagnant pockets of water.

9) Canals should not be cut into an aquifer.

10) Avoid constructing canals which shunt nutrients from urban areas directly into water bodies.

11) Natural levees should be allowed to remain between constructed spoil levees, so that the natural "sheet flow" hydrology is intact. A 1:1 ratio seems desirable.

VI. Management Data Needs

On the basis of the information reviewed in this paper, our experiences with the biology of Louisiana's marshes and our understanding of coastal zone management needs, we feel that the following data should be developed in order to more fully comprehend the magnitude and implication of land loss:

A. Canals apparently are an important factor in land loss (e.g. Figures 8 and 10). This needs to be investigated more thoroughly. Especially important is the further documentation of:

1) Canal density and land loss in relationship to different substrate, vegetation and hydrologic regimes.

2) Canal widening vs. width over long periods of time.

3) Wetland losses as a consequence of different spoil disposal practices.

B. The couplings of sediment sources, sinks, and hydrology need to be further explored in order to develop a clearer perspective of the consequences of man-made changes in hydrology, especially the cumulative impacts.

1) What is the impact of "channel" widening and deepening at barrier island inlets on the hydrology of an entire hydrological unit? Obvious case studies are the Calcasieu ship channel, the Mississippi River Gulf Outlet near New Orleans; and the Barataria Bay Waterway.

2) How will different schemes for "controlled diversions" of sediment-rich water affect the entire basin?

C. Planning for management of the newly emerging Atchafalaya Delta should begin "in toto" now. This is new land owned entirely by the people of the state of Louisiana. A piecemeal management approach for the temporary benefit of a few interest groups is in the long-run unsatisfactory. A long-term planning perspective is necessary to optimize its potential benefits -- economic, social, environmental, recreational, cultural and others.

D. The couplings within wetlands need to be more fully appreciated. No project should be approved without considering its impact on the entire hydrological units. In particular:

1) Public agencies need a clear documentation of these couplings.

2) The natural work services of wetland should be considered in evaluating project impacts -- especially the long-term impacts on biological productivity and what is known as "secondary impacts" which accompany successful project development. An outline of these probable secondary developments is needed for a more complete basis for planning.

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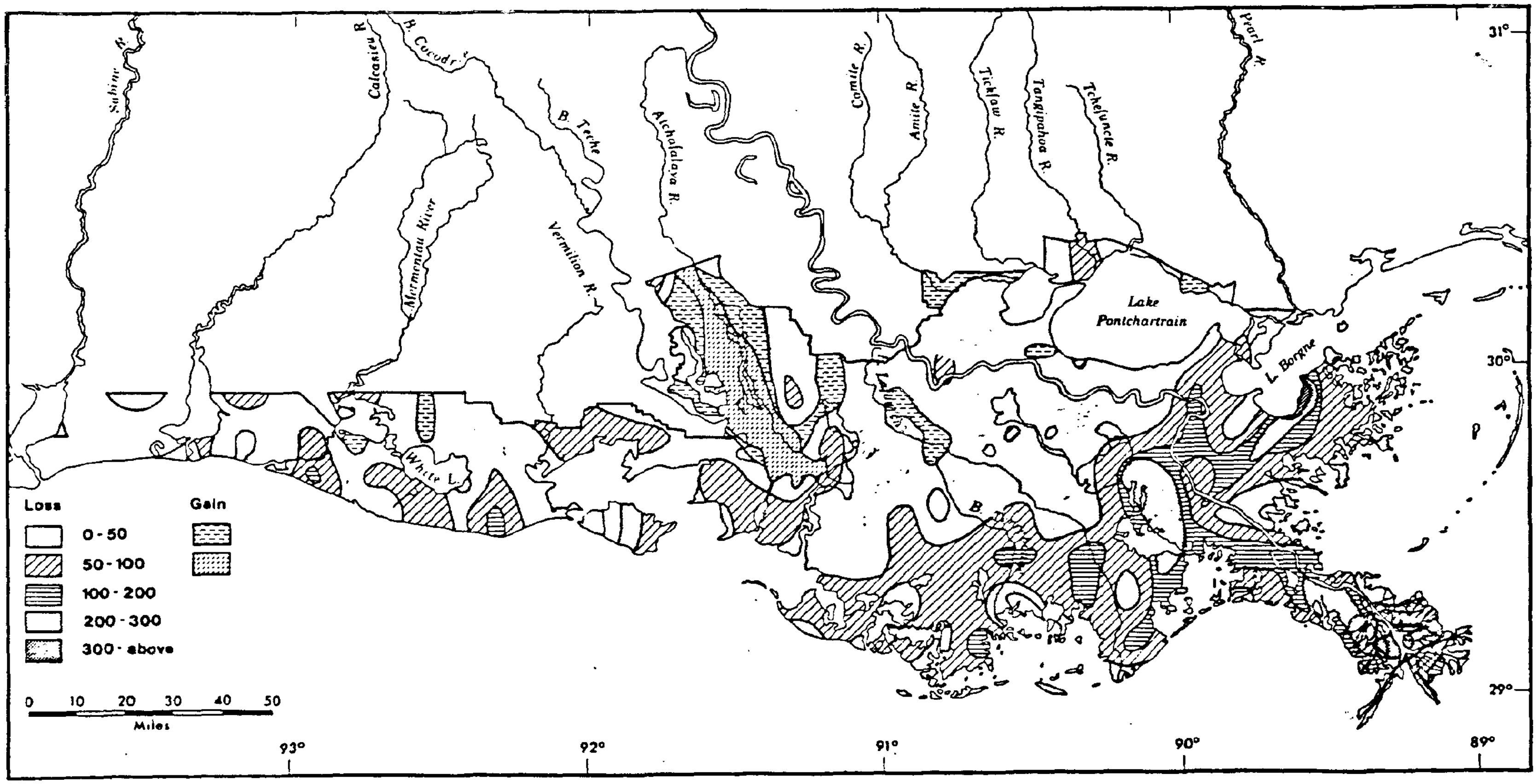

Fig. 1a. Land loss and gain in the coastal zone.

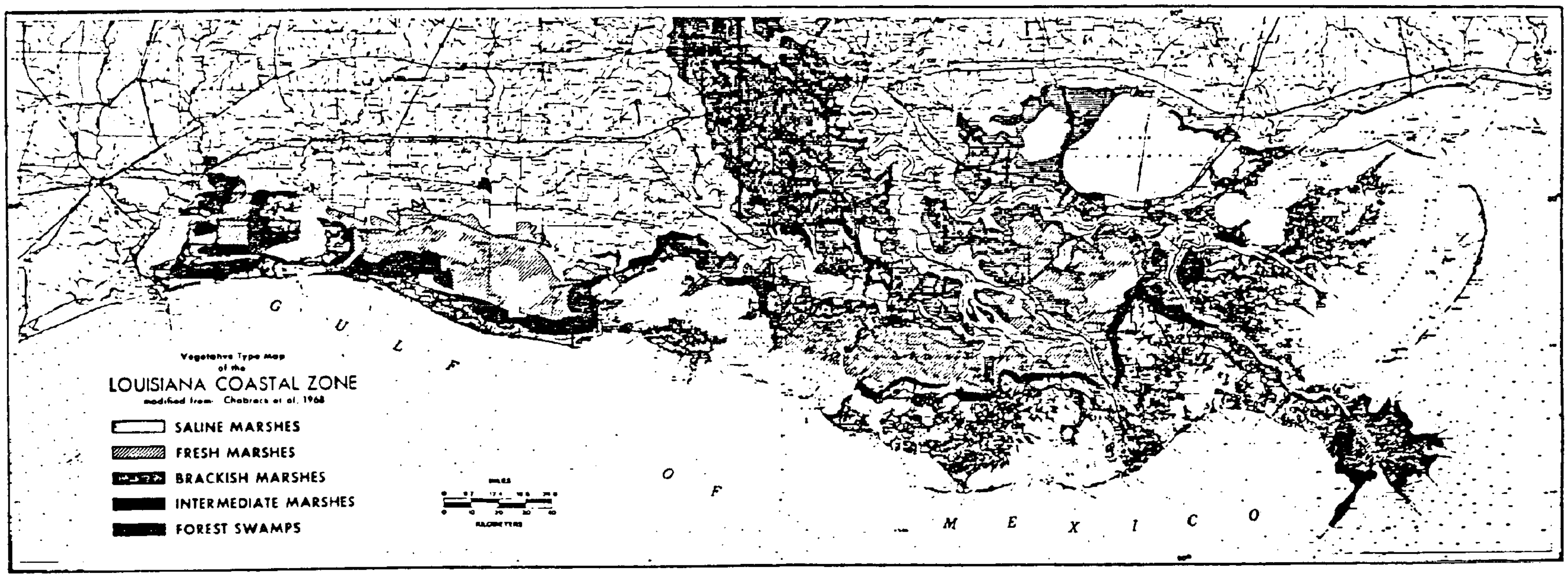

Fig. 1b. Vegetative types in the coastal zone.

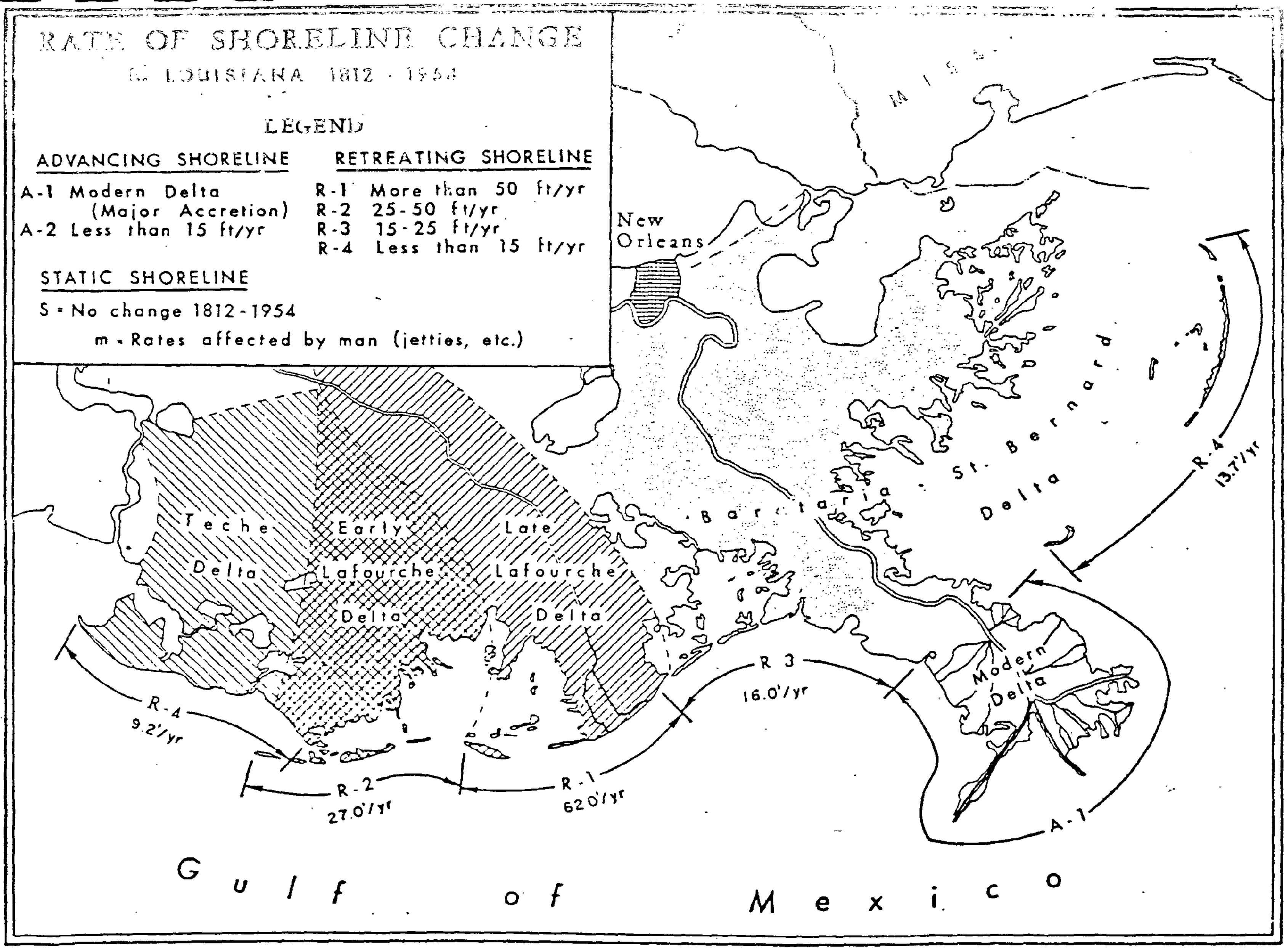

Fig. 2. Rate of shoreline change.

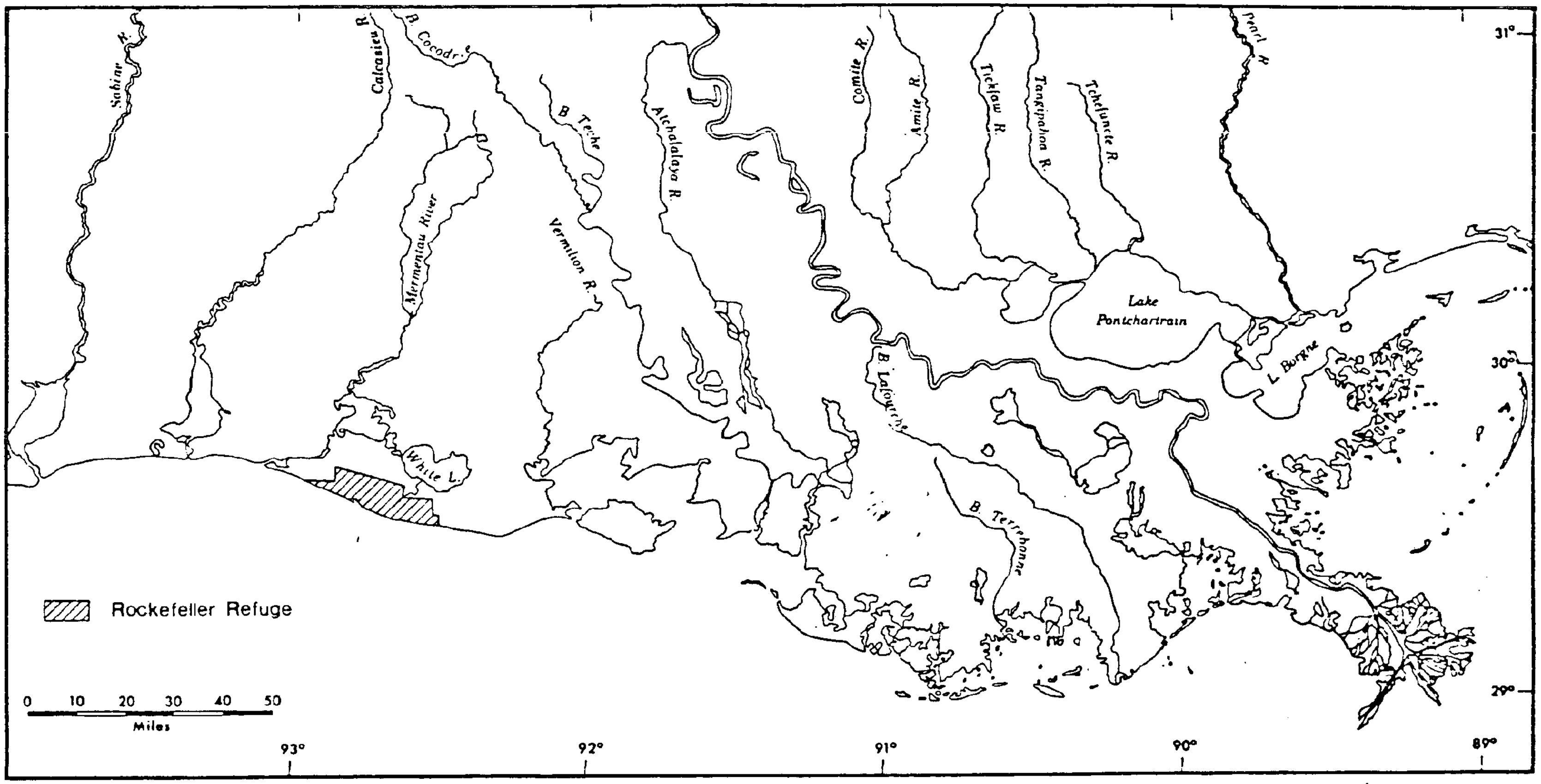

Fig. 3. Rockefeller Refuge on the Chenier Plain.

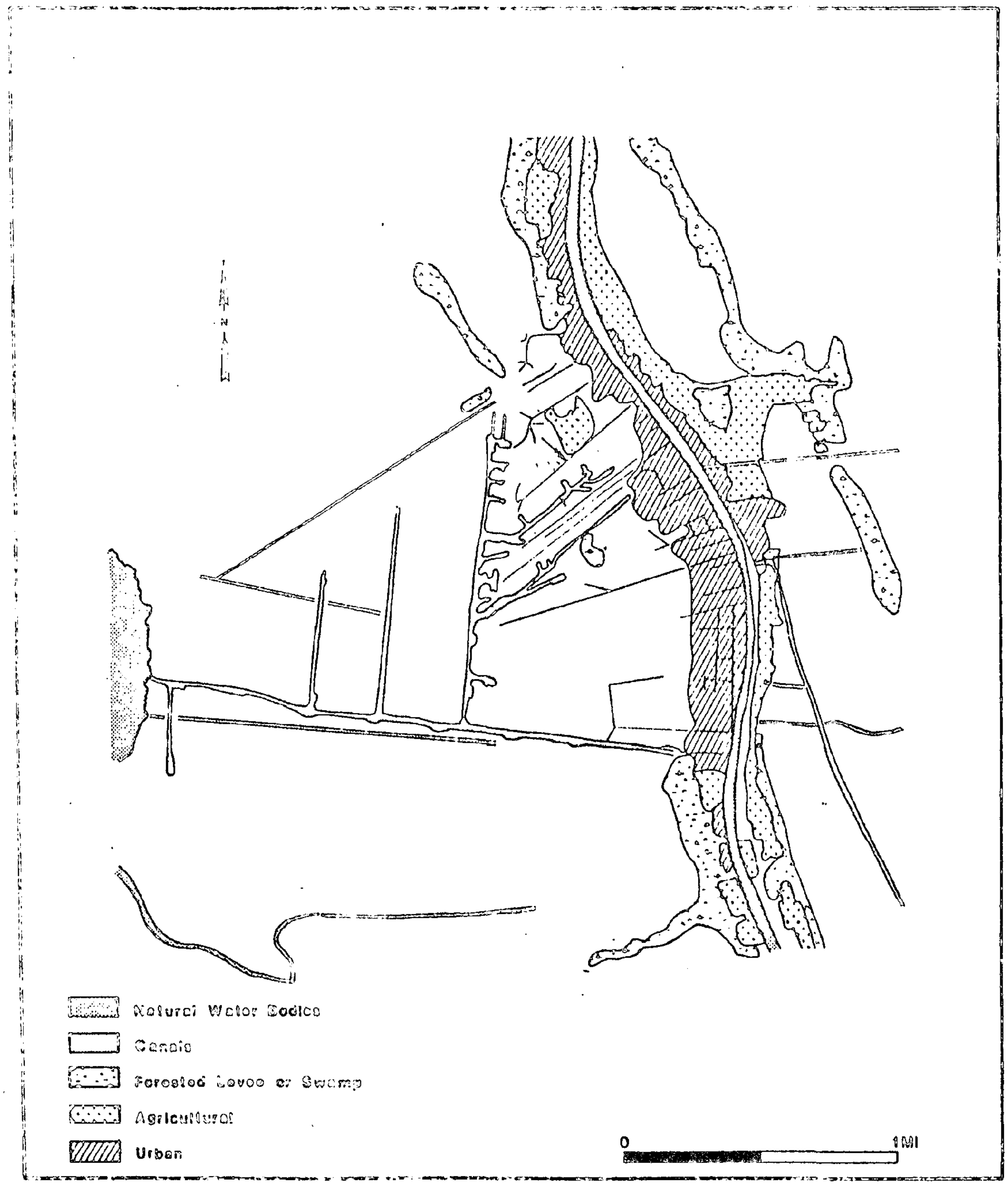

Fig. 4. Golden Meadow Oil Field, 1940.

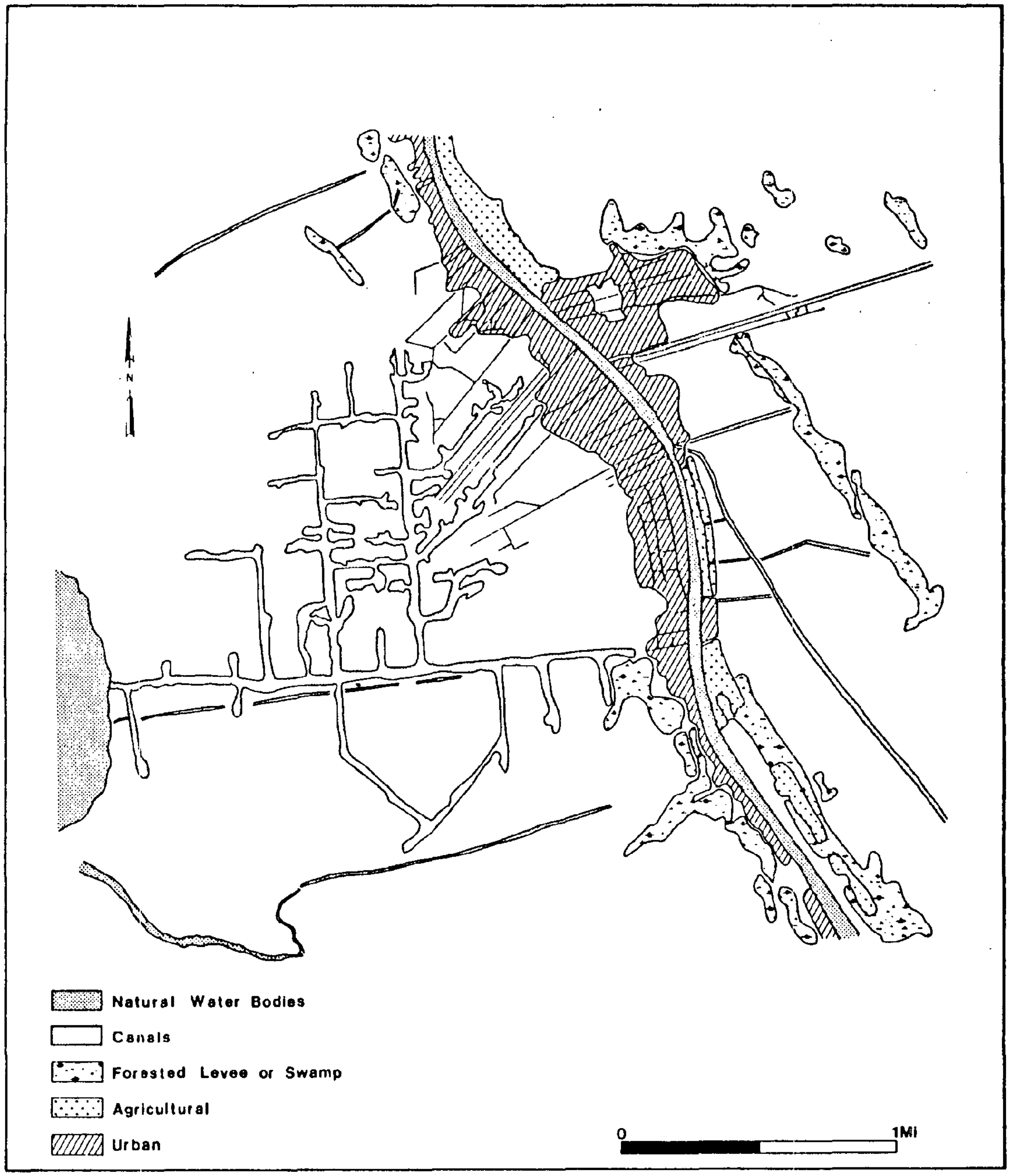

Fig. 5. Golden Meadow Oil Field, 1953.

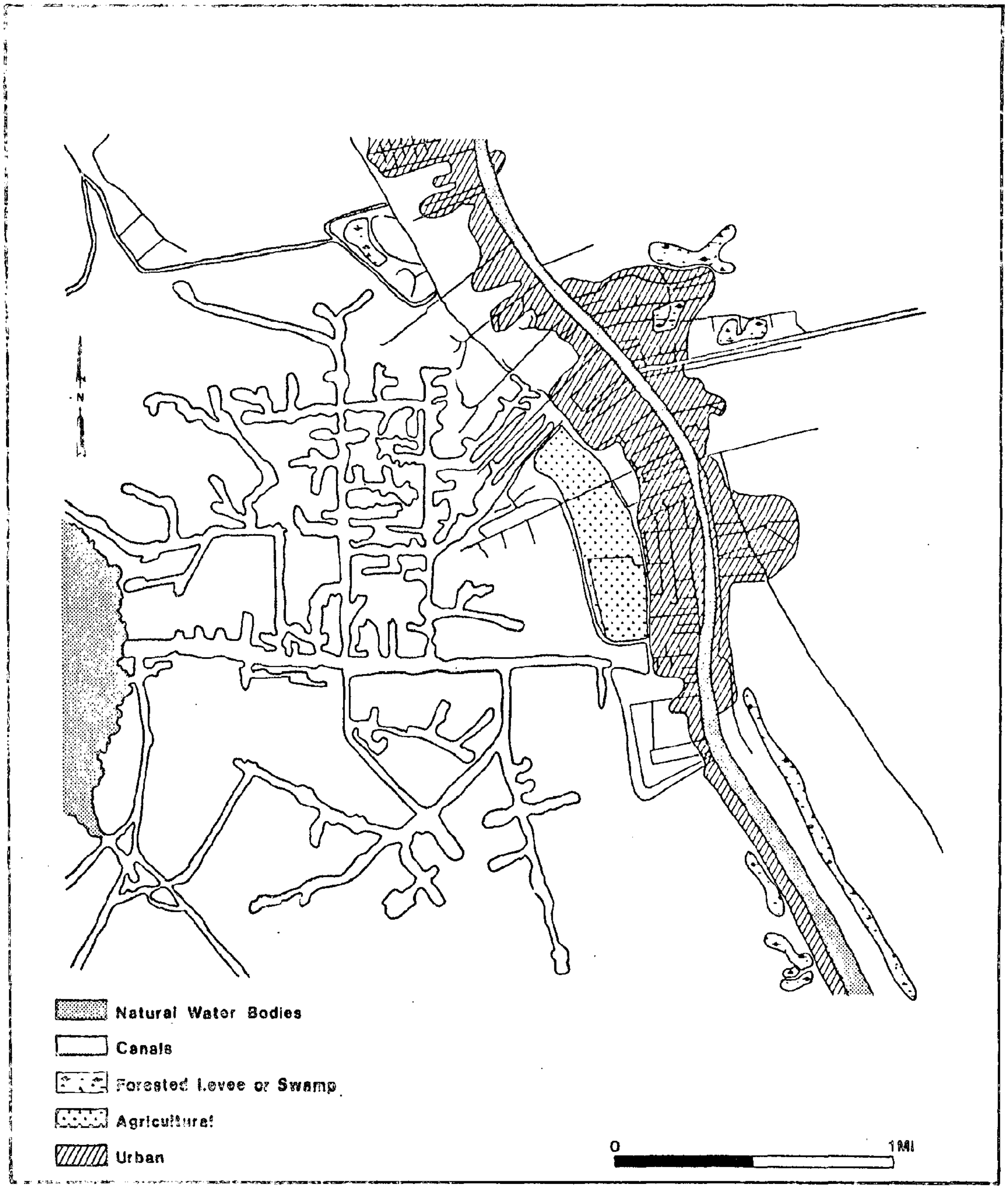

Fig. 6. Golden Meadow Oil Field, 1969.

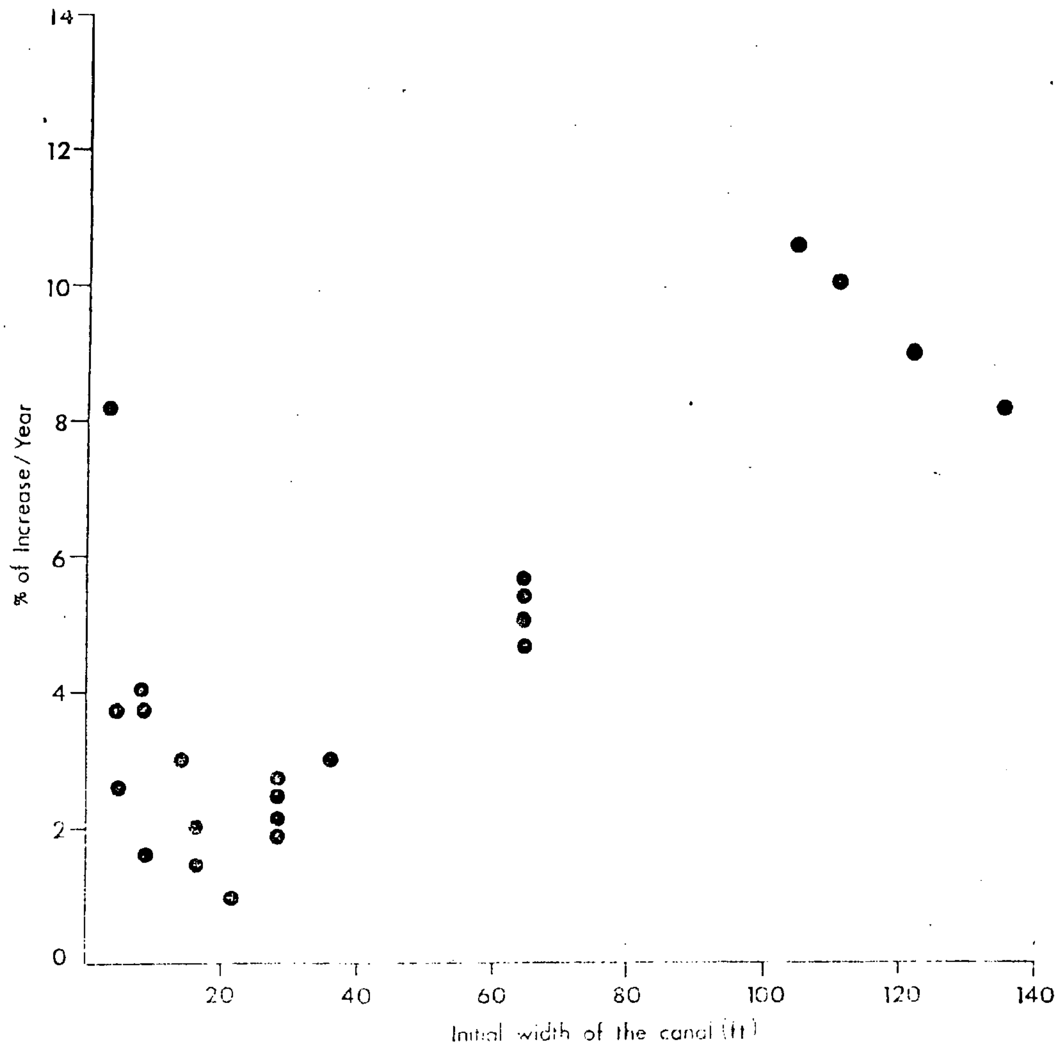

Fig. 7. Relationship between size and increase in width of canals.

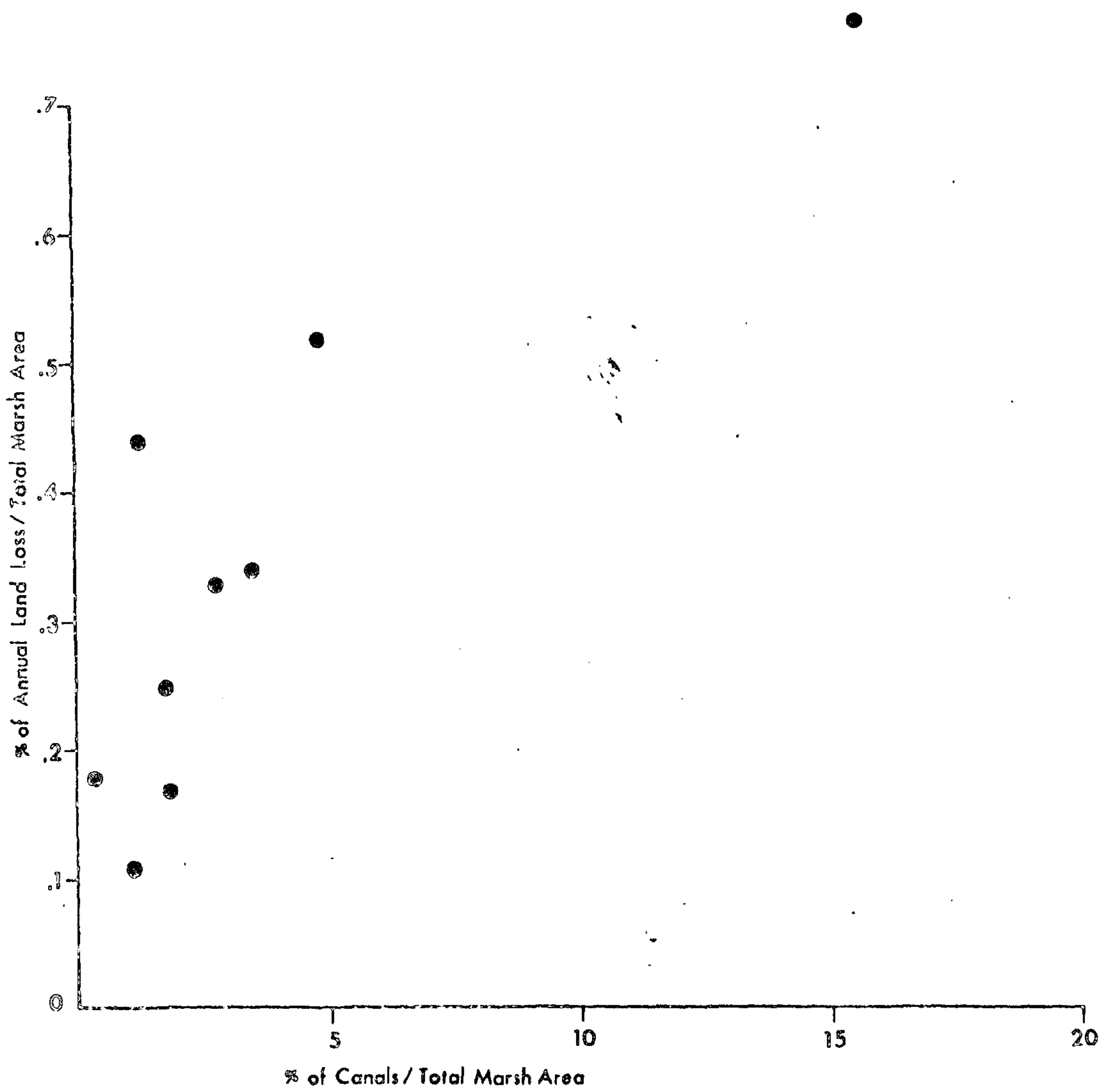

Fig. 8. The relationship between density of canals and the average annual land loss in coastal Louisiana from 1930-1969.

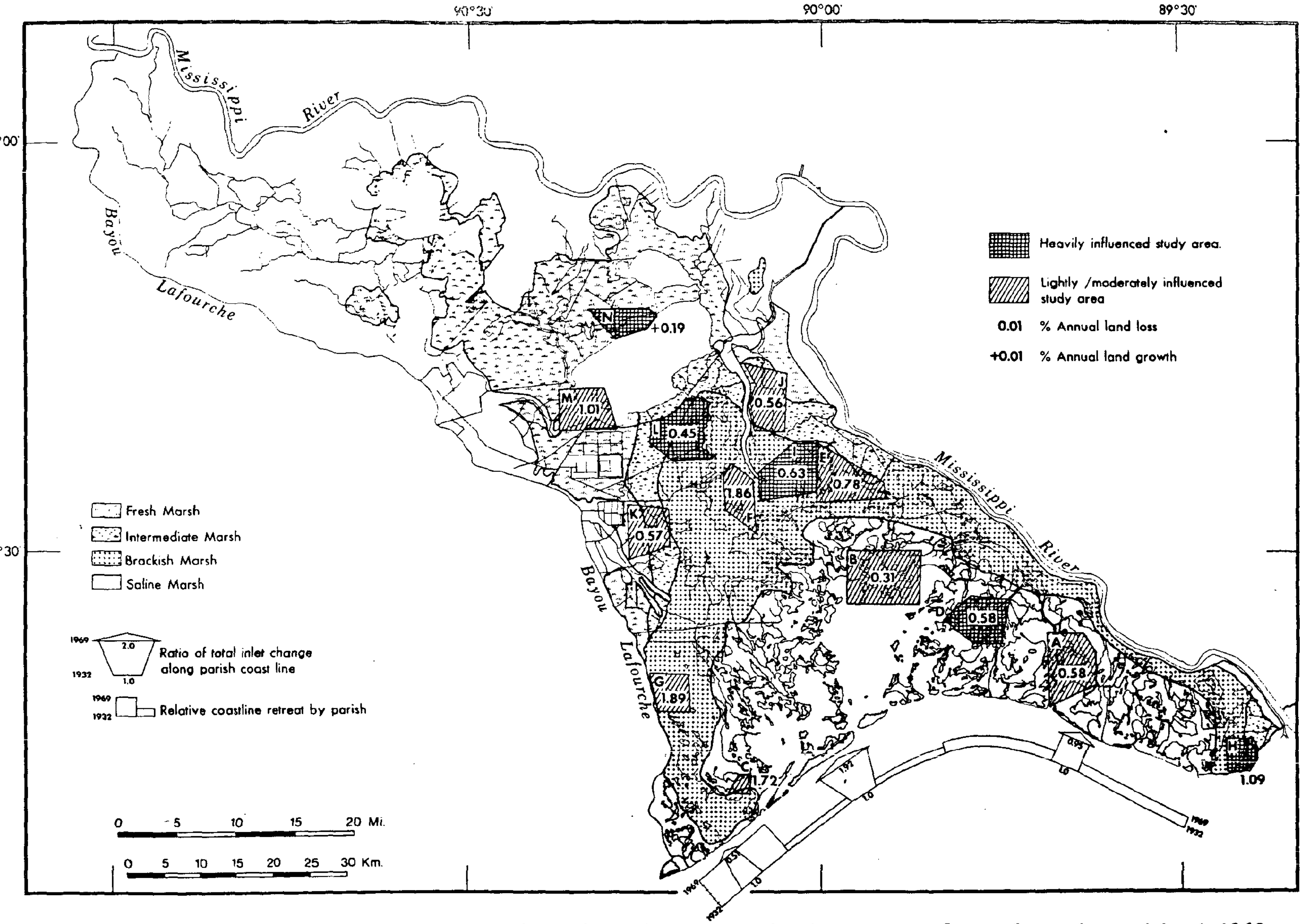

Fig. 9. Areas of south Louisiana investigated to determine absolute area of canals and marshland 1960-1974. Aerial photomosaics used (Adam et al. 1976).

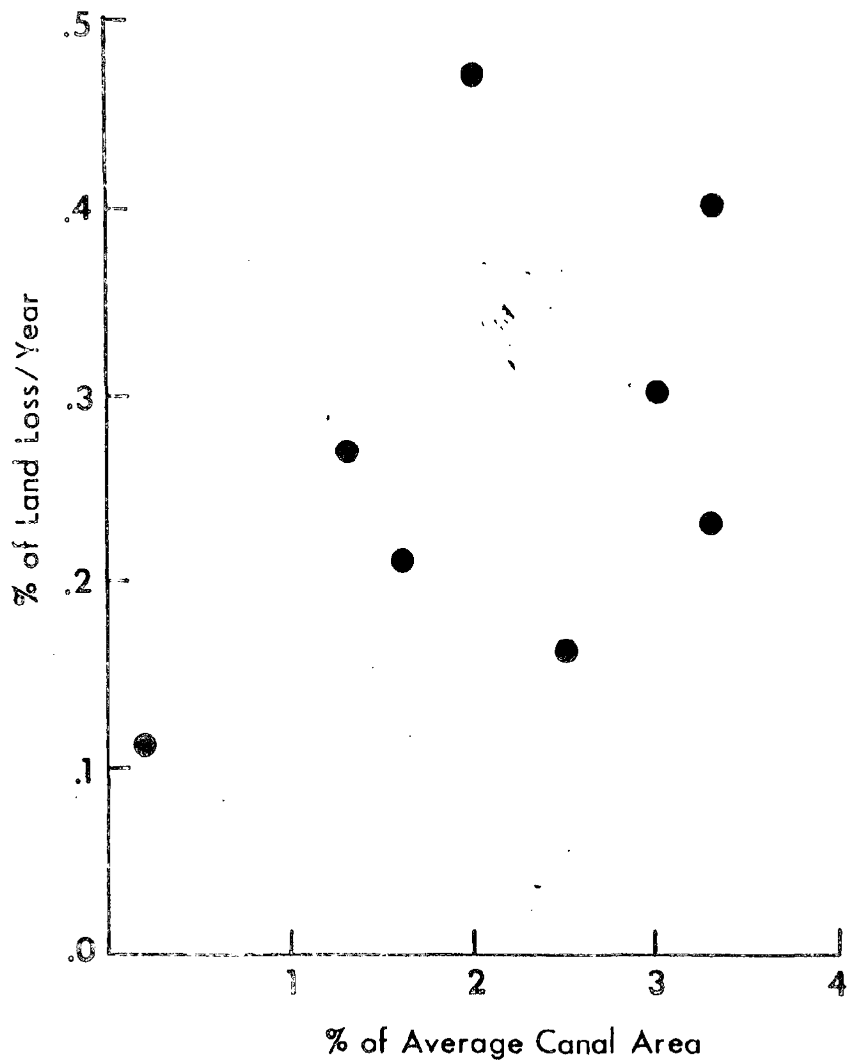

Fig. 10. Relationship between canal density and land loss from 1960-74 for each area shown on Fig. 2. Land areas determined from aerial photographs.

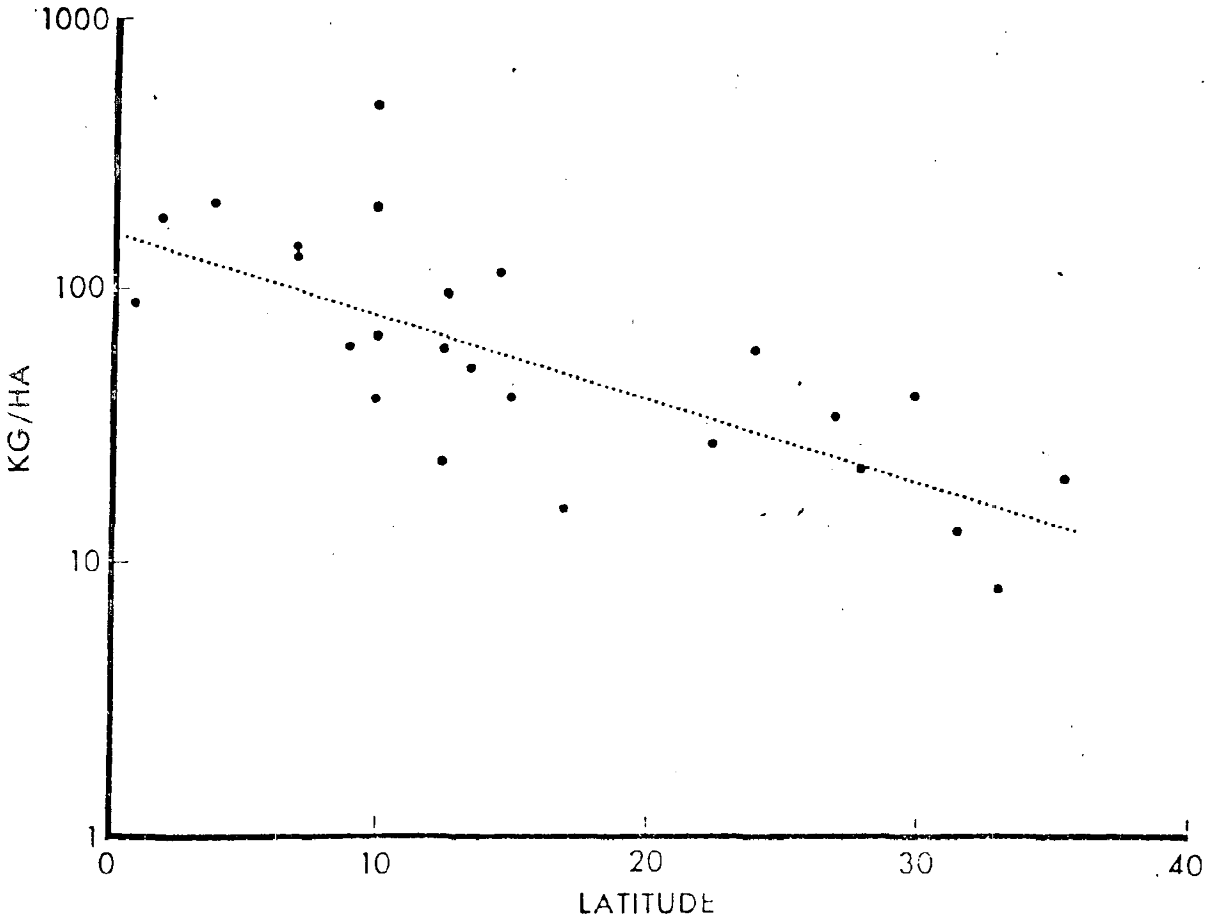

Fig. 11. Relationship between shrimp yields and wetland area on a world-wide basis (after Turner 1977).

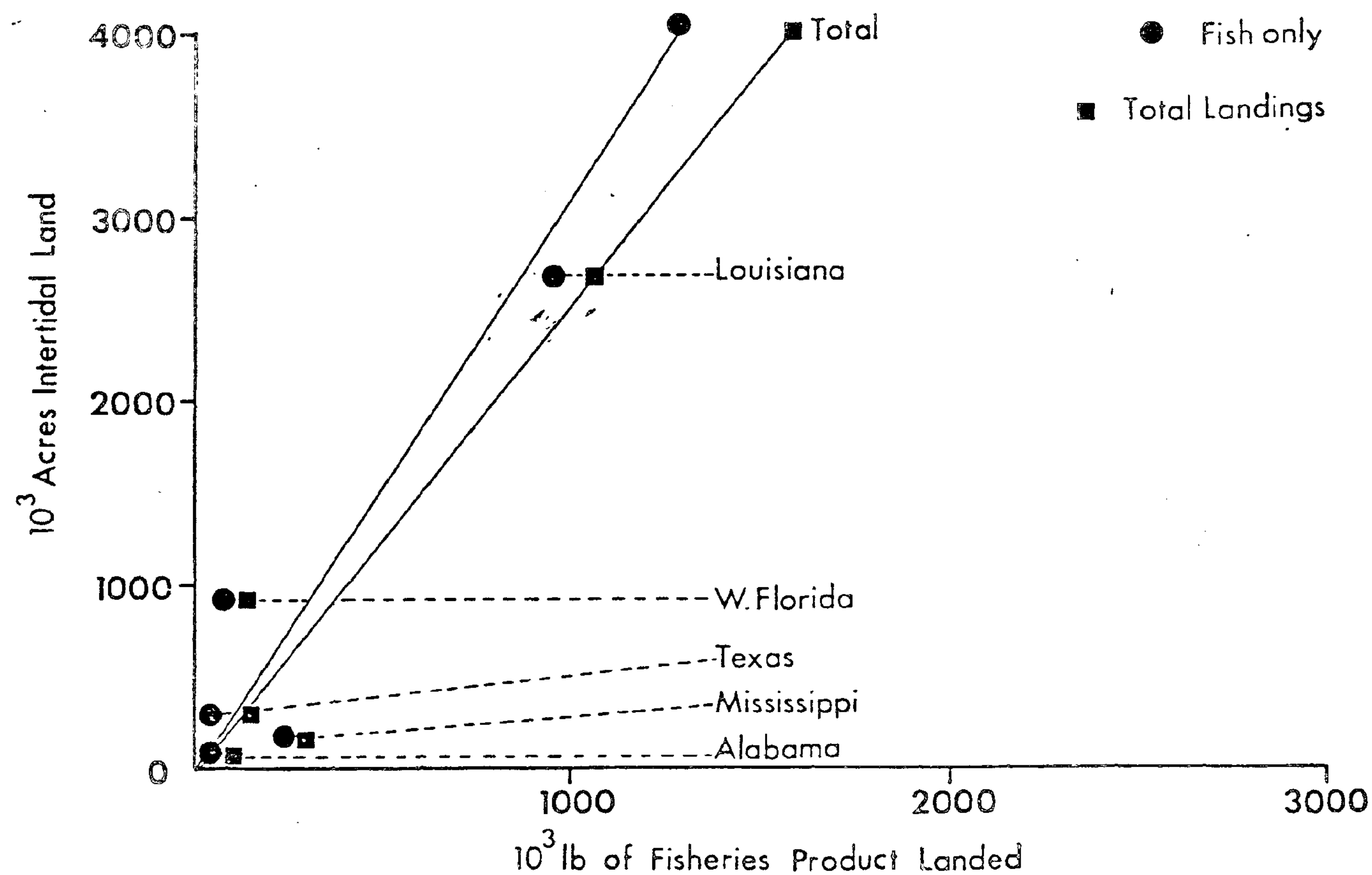

Fig. 12. Relationship between fisheries ydelds and intertidal areas for the Gulf of Mexico.

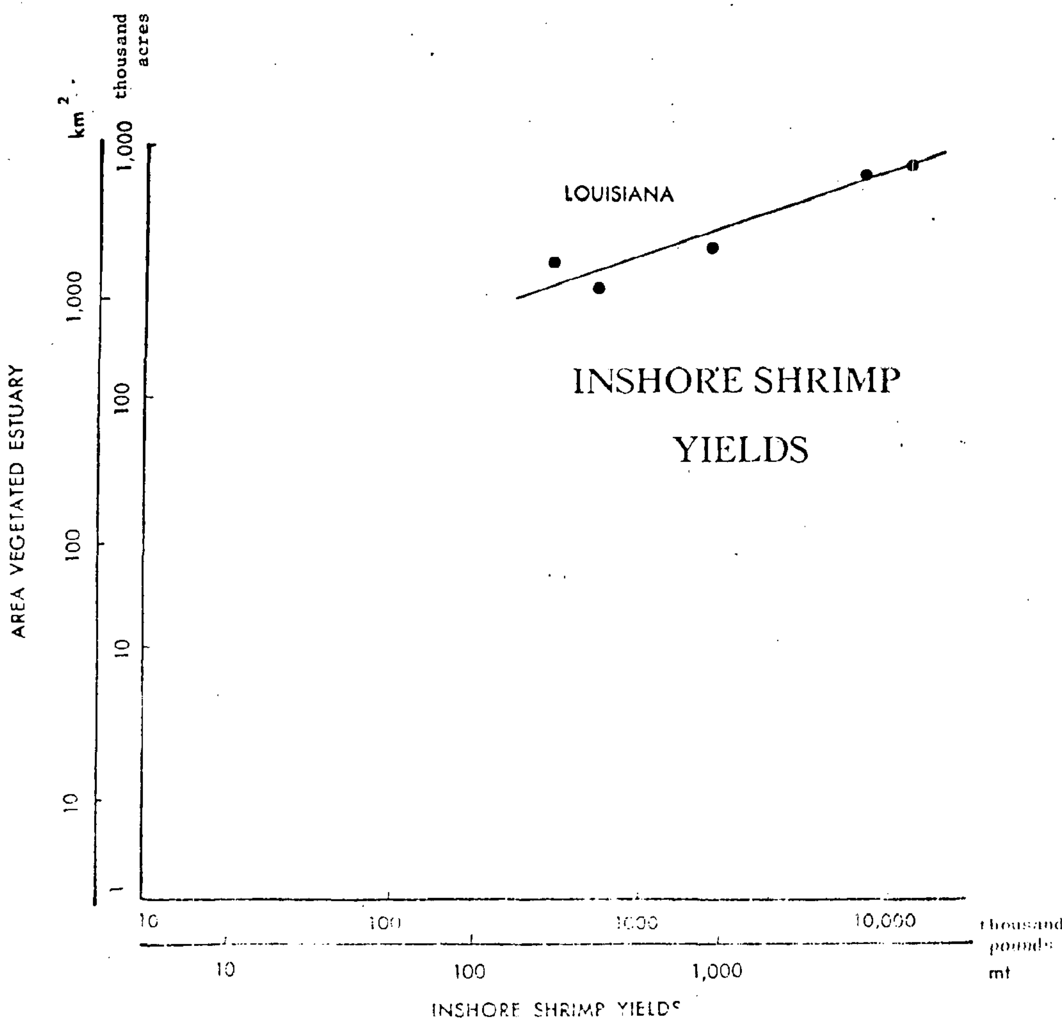

Fig. 13. Relationship between average inshore shrimp yields and marsh acreage in several hydrological units of Louisiana (after Turner 1977).

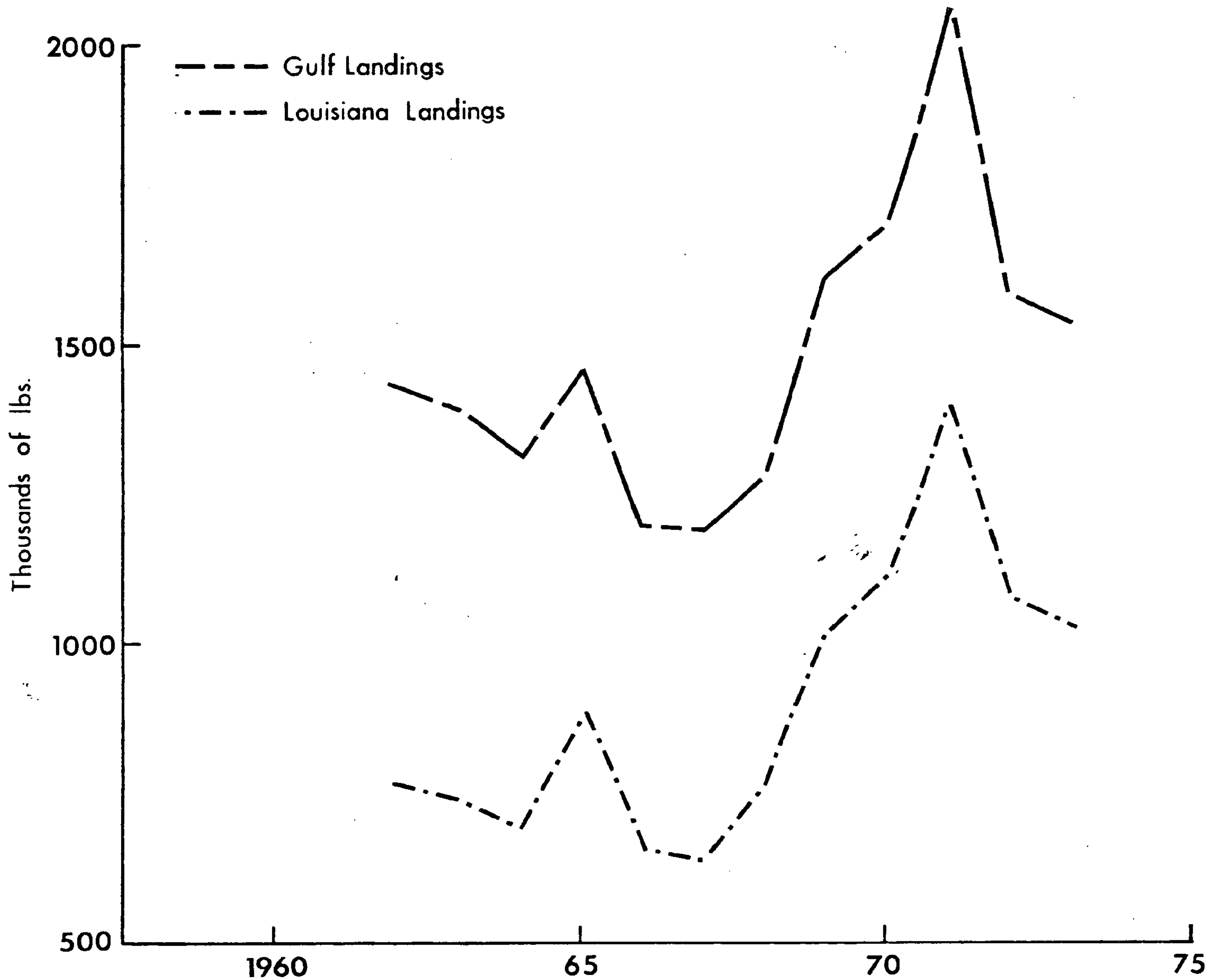

Fig. 14. Recent landings for Louisiana and the Gulf of Mexico (U.S. only).

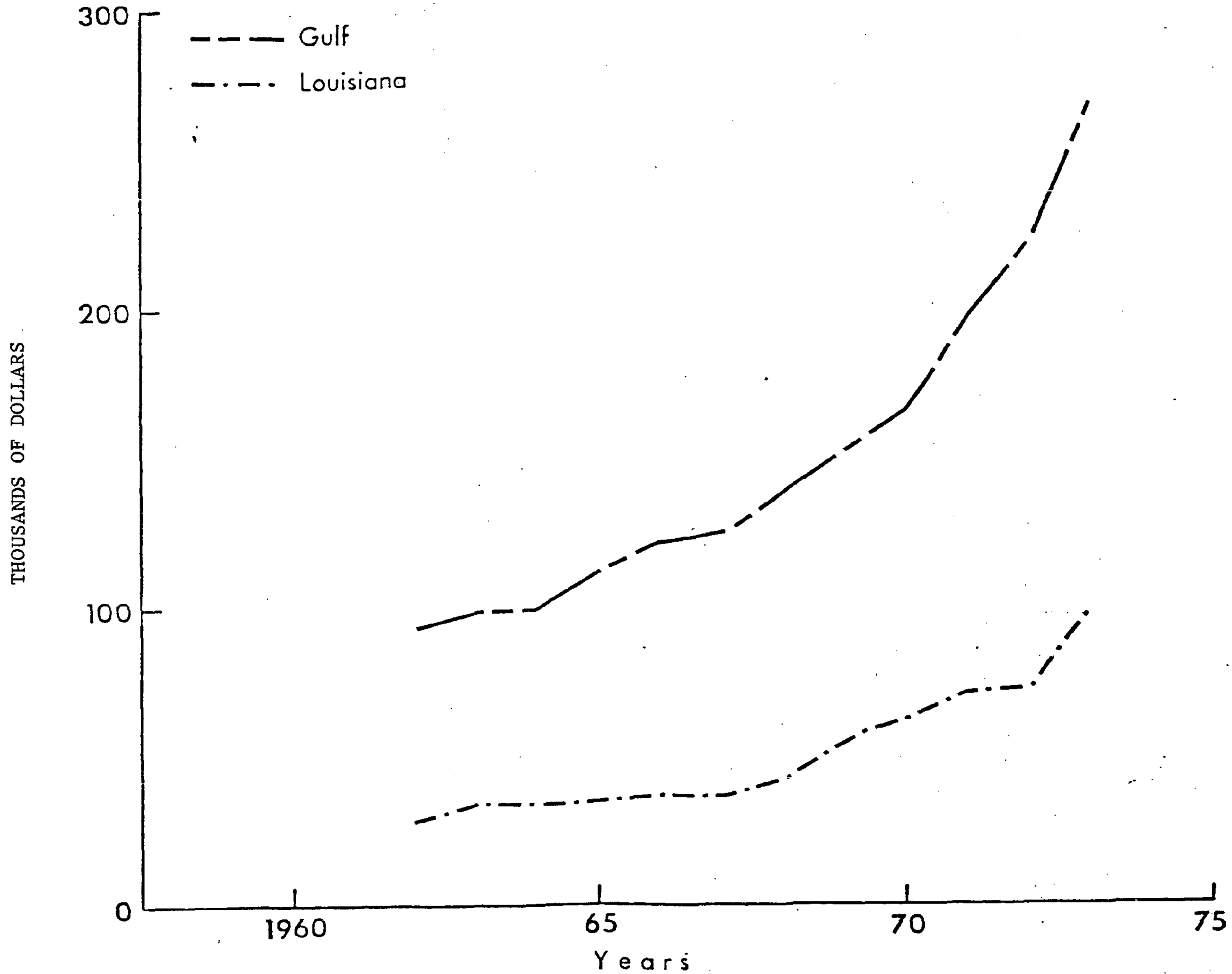

Fig. 15. Recent value of fisheries landings in Louisiana and for the Gulf of Mexico (ex vessel).

ACKNOWLEDGMENTS

Efforts toward implementation of coastal zone management in Louisiana have enlisted the interest and participation of many public agencies and institutions. As a cornerstone for this program, scientific information from every available source is being compiled and digested in a series of Coastal Zone Management reports. The collection is ultimately intended as an authoritative central reference source for persons involved in administration of an operational CZM program.

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